SUM4Re

Creating materials banks from digital urban mining

D6.3 Social-Environmental analysis

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SUM4Re

Creating materials banks from digital urban mining

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EXECUTIVE SUMMARY

T6.3 Sustainability Analysis of Elements of Circular Economy. (M8-M17) BLOCKM; THUAS

The value of secondary materials is not only relevant in financial terms, but also in social (environmental) terms. And not just regarding the use of secondary materials, but over the entire life cycle of a material, including periods of processing, repair, or store.

The central element in a Sustainability Analysis of Elements of Circular Economy is the fact that “if we can reuse materials, we do not have to produce new materials”. This saves about 50% of all embedded CO2 constructing and using building during the whole lifespan. Combining saved CO2-emissions with the Emissions Trading System and CO2-rights will also provide the economic value of ecological savings.

GLOSSARY

Terms, Abbreviations, and Acronyms

DBL	Digital Building Logbook
DPP	Digital Product Passport
EU	European Union
EPR	extended producer responsibility (EPR)
ICT	Information and Communication Technology

TABLE OF CONTENTS

1. Introduction

The holistic approach from T6.2 also means that values of secondary materials are relevant in terms of social (environmental) value, and not just regarding the use of secondary materials, but over the entire life cycle of a material, including periods of processing, repair, or store.

The central element in this approach is the fact that “if we can reuse materials, we do not have to produce new materials”. This saves about 50% of all embedded Co2 constructing and using building during the whole lifespan. Combining saved Co2-emissions with the Emissions Trading System and CO_2-rights will also provide the economic value of ecological savings.

This task will analyse the benefits of the proposed circular economy from an environmental point of view [BLOCKM]. This will be done in section 2

THUAS will research into the interaction between law and economics to remove obstacles for circular use of secondary materials. This will be done in part 3

2. The role of Blockchain technology within Digital Material Databases and the Sustainability Elements of a Circular

2.1. Introduction

Reusable materials both have a social and a financial value. The social value of materials is broader than the financial value of materials, because the social value also includes those qualitative benefits that cannot be directly recorded in monetary units. An example of these externalities is the value of saved CO_2 emissions that go hand in hand with the reuse of materials from a building because the reuse of materials avoids the realisation of new materials and the environment is not further affected.

Materials can only have a value if these materials can be used in an alternative way. This means that they can be detached without much damage and can once again provide a function in a real estate object with complete information for the buyer and seller. This is explained in detail in chapter 5 of the Handbook Circular Demolition, which is an Annex to this deliverable.

The Blockchain Module in Block Materials Digital Materials Logbook Cirdax offers a tool that strengthens the use of property right of materials in the Digital Materials Database. It is only effective if it can be used in combination with a Material Passport. Each Material has its own Material Passport, which gives this material its identity. The identity can be verified by registering the ownership of the passport in the blockchain, which also gives the possibility to see that registration as a property right at the time of registration. The blockchain registration serves as a property right that is also included in the material passport by means of its hash, i.e., the blockchain identity of the material passport.

The blockchain registration establishes ownership rights on the materials. Ownership rights give us the opportunity to link these to other rights, such as CO_2 rights, or to sell these rights to other stakeholders. The combination of materials with an identity (Universal Unique Identifier or UUID), the verified blockchain registration and the characteristics of ownership rights, give us the opportunity to link materials to marketplaces and future contracts, because the immutable nature of information in the blockchain can also manage issues such as liability and duration. We always know who owns the materials. This is particularly important if we want to check over time who owns a material and is then responsible or liable for the economic and social value behind a material. In this way we can also organize an important social or environmental task about the circular requirements for materials. Both in terms of delivery and the quality of the materials in the future, so we avoid using new materials, and save all kind of emissions. See also paragraph 2.10 in the Handbook Circular Demolition, in which we have given a description of factor time within the process of circularity of the built environment.

To arrive at a social value assessment of reusable materials, the following input is desirable:

a. The different properties of a material
b. The quantitative size of a material
c. The degree of detachability, that is, the alternative applicability of a material.
d. Limiting characteristics of a material for reuse.
e. The ownership or blockchain registration of the materials.
f. Calculation methods relating to the “embodied CO_2” of materials.
g. Materials valuation methods.
h. Market information about the alternative price of materials in a market.

2.2. Products and services

The first product that serves the social valuation of the materials in a building is the CO_2 balance of a building. This product provides the sum of all CO_2 savings that are accomplished with the reuse of materials in a building. The CO_2 balance of a building combines the following elements, namely:

a. The size of each specific material in a building.
b. The ability to remove the material undamaged.
c. The “embedded CO_2” in the realization of new equal material at a standard weight.
d. Multiplying the actual weight of the materials with the “embedded CO_2” for each material.
e. The sum of all multiplications of all materials for the registered (in blockchain) owner in saved CO_2 in alternative use.
f. The market value of this CO_2 saving by multiplying the amount of CO_2 saved by the trading price of Co2 rights, in accordance with the European Trading System of CO_2 (See eex.com; price of CO_2 rights as of September 18 2025 = € 77.22)

The second product that serves the social valuation of the materials in a building is the Materials Balance of a building. This product provides the sum of all direct market values of the materials in an alternative application, such as can be obtained on a marketplace.

The Material Balance of a building combines the following elements, namely:

a. The size of each specific material in a building.
b. The ability to remove the material undamaged.
c. The price of a material on a reusable materials market.
d. Multiplying the current weight of the materials by the market price for each material in euros.
e. The sum of all multiplications of all materials for the registered (in the blockchain) owner in euros.

The third product that serves the social valuation of the materials in a building is the Social Materials Balance of a building. This consists of the sum of the CO_2 balance and the Materials balance of the building.

The result of the social valuation of a material is the representation of the actual value of a registered material in a digital materials database, which is also provided with a right of ownership by means of a blockchain registration. The sum of the various property rights of materials in a building can be summarized in the material balance of a building. If the CO_2 value of the saved CO_2 emissions is added to this, the sum of this material and CO_2 balance forms the Social Materials Balance of a building.

Within the DBL Cirdax, templates are available with which the calculations of the value of the products can be filled in. These calculations are based on the inventoried materials, for example on the Pilots in SUM4RE in Den Haag, Svalbard and San Sebastian.

2.3. Embodied CO_2-savings and other possibilities

The “embodied” CO_2 savings can be collected using various databases and reflect the following components for each material, as shown in the figure below:

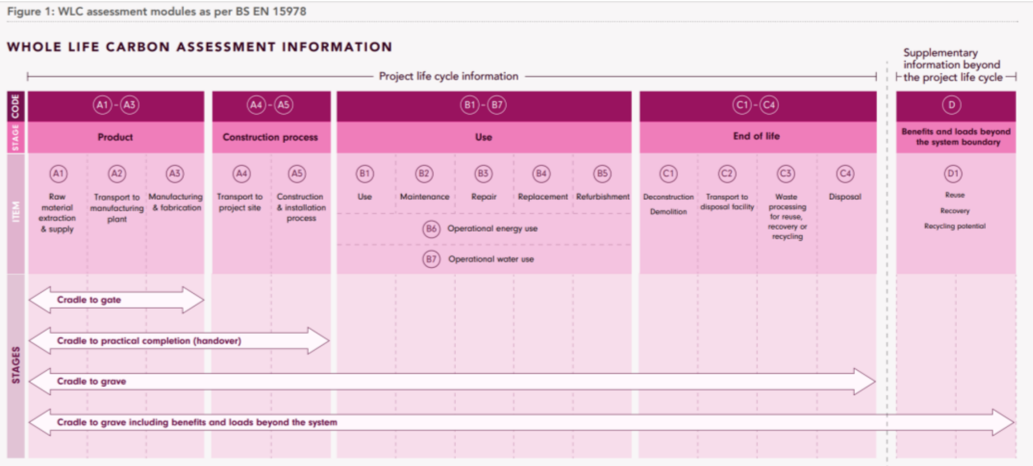

Figure 1.

One of these databases is the ICE database(the Inventory of Carbon and Energy Database), built by the University of Bath in the United Kingdom. The CO_2 calculations that are in the ICE-database are linked to the Digital Materials Logbook Cirdax as an example of what kind of supporting information can be enclosed for stakeholders in a Circular Economy. These Co2-calculartions can be connected to the tools and interventions assessed in SUM4RE. Like presented in the KPI's for SUM4RE as a whole and in the results of task 1.6, where saved Co2-emissions as a result from reusing materials are relevant. The calculation of the embodied environmental value assessed is also based on the assessment of the effort required to restore material and the repair efforts required for its reuse. It reflects the potential avoidance of CO_2 emissions, waste, and energy, as well as potential material reuse.

In France, when calculating the CO_2 savings for an old building, the LCA methodology established by the French government using the INIES database and the FDES is used. The CO_2 savings are estimated equal to the CO_2 emissions of a new product that we would have to buy if the material could not have been reused. A methodology (for Bordeaux Metropole) has also been developed by Nobatek to evaluate the effects of reuse approaches.

The combination of a DBL like Cirdax, new technologies like Blockchain to secure property rights and environmental information embedded in a new institutional way of organizing a circular economy brings us an economic framework for a circular economy, that is really circular in practise. The big challenge of course is how the organisation of material passport that have those property rights can be sped up.

2.4. Quality factors

The calculations of the Social Value of the materials in a building are based on a transparent quality of the materials. However, this can encounter problems in practice, for example because of the presence of toxicity in certain materials. In that case, materials cannot be used as alternatives, even though they can be separated. Another factor is that the product/material is not matching new standards (size, flammability). Although it is still of good quality and removable.

Another factor that influences the social value of materials is the existence of a market for reusable materials. Markets for reusable materials are currently dependent on the access of buyers and suppliers in a certain geographical region to this market, and on the transparent quality of the materials demanded and supplied. The more transparent the quality, the more buyers and suppliers will value this market, which will ensure that the value of new and reusable materials of a specific type will approach each other.

The prices of reusable materials in a building on a market are the product of both the intrinsic value of these materials, and the processing and treatment costs of these materials to give them an alternative destination. In business economics terms, the value of a reusable material in a building will be lower than the value of a freely available material on a market, because in the latter the various handling costs are also included in the market price.

However, if the saved CO_2 through reuse can be included in the pricing of reusable materials, this increases the value of the materials in a building. If the CO_2 value of a material is equal to the handling costs of a material to make it freely usable again in an alternative use, the market value of reusable materials can be set equal to the market value of primary materials, such as on a public marketplace (wholesaler for building materials).

For the time being, the saved CO_2 through reuse cannot be converted directly into euros. However, calculations can be made as if this were possible. In addition, research has been requested into the size of the handling costs for the removal of materials, so that they are reusable with the desired quality. Research into the purchase prices of reusable materials by "harvesters" of building materials is another important component, which amounts to the quality of prices on markets for reusable materials in buildings.

3. The interaction between law and economics to remove obstacles for circular use of secondary materials

A circular market for secondary materials only scales when legal certainty, economic incentives, and effective governance reinforce each other. Legally, the critical gate is the transition from waste to product status under the EU Waste Framework Directive via end-of-waste criteria. When these criteria are clear and uniformly applied, transaction costs fall, due diligence requirements shrink, and banks and insurers are more willing to underwrite reuse. When criteria are fragmented across jurisdictions, however, even high-quality secondary materials remain “unbankable.”

Economically, secondary flows struggle because market prices do not reflect externalities: virgin materials benefit from subsidies, sunk scale advantages, and unpriced CO_2, while reuse bears additional costs of testing, processing, and storage. Instruments that internalise externalities—such as carbon credits for avoided embodied emissions, reduced Value Added Tax on verified secondary content, landfill taxes, and minimum recycled content requirements under extended producer responsibility (EPR) regimes—can align private returns with societal objectives (OECD, 2019; European Environment Agency [EEA], 2021).

Yet, legal and economic measures are only effective when supported by stable governance frameworks. Fragmented responsibilities between municipalities, regulators, and private actors dilute property rights and raise uncertainty, much as Duindam and Waddington (2010) found in cross-border land governance. In the construction sector, similar fragmentation undermines the long-term value of secondary material markets. Effective solutions require inter-municipal or regional authorities to provide collective certification, standardise contractual templates, and ensure mutual recognition of DMPs and blockchain registrations. Evidence from waste management confirms that inter-municipal companies are more resilient and effective than loose associations because they create enforceable commitments and protect long-term value (Bel & Warner, 2015; Villalba Ferreira, 2022).

From a law and economics perspective, securing property rights in materials over time is essential to reduce transaction costs and attract investment (Coase, 1960). Blockchain-anchored DMPs allow materials to carry a durable legal-economic identity, enabling futures contracts, liability allocation, and warranty schemes. But for such systems to function, governance institutions must coordinate across municipalities and borders, ensuring consistency and trust. In this way, law, economics, and governance interact as a three-legged stool: without governance institutions to stabilise cooperation, legal clarity and economic incentives alone cannot deliver circularity at scale.

The effectiveness of law-and-economics instruments also depends on the availability of robust information. Without reliable data, property rights cannot be enforced, liability cannot be allocated, and incentives cannot be credibly linked to material performance. Here, SUM4RE plays a pivotal role by providing verified information flows—linking material passports to blockchain records, generating CO_2 and material balances, and validating quality through pilot-based inventories. This information generation is not only technical but also institutional: by standardising how data are produced and shared across municipalities and markets, SUM4RE strengthens the governance frameworks needed for cross-border recognition and collective enforcement. In this way, the project bridges the gap between legal rules and economic incentives, ensuring that circular use of secondary materials is not merely an ambition but a practicable, enforceable reality. SUM4RE not only provides a means to ensure the quality of materials. It also ensures that more materials can be reused, since the common practice only relies on a visual inspection.

While regional and inter-municipal cooperation is essential to overcome fragmentation and create stable governance frameworks, scalability requires aligning information flows, regulations, and market incentives at the European level. Only when Digital Material Passports, blockchain registries, and end-of-waste criteria are interoperable across Member States can secondary materials circulate freely in the EU's single market. This scalability is also critical for labour productivity: shared standards reduce duplication in certification, speed up transactions, and create economies of scale in training, auditing, and market access. In effect, the European level provides the institutional layer that can transform scattered pilots into a coherent market for secondary construction materials (European Commission, 2020). SUM4RE contributes to this scaling process by piloting interoperable digital passports and testing governance models that can inform EU-wide adoption.

At the same time, the circular economy for construction materials cannot remain a European project alone. Global competition, especially from producers of virgin materials operating under less stringent environmental regulations (e.g., in China), creates downward pressure on secondary material markets in Europe. If European rules internalise CO_2 costs while global competitors do not, this risks carbon leakage and market distortion. Therefore, national and European incentives must connect to global governance mechanisms. Instruments such as the Carbon Border Adjustment Mechanism (CBAM), introduced in 2023, aim to address this challenge by levelling the playing field for carbon-intensive products entering the EU (European Commission, 2023). More broadly, international cooperation on embodied emissions, environmental product standards, and trade policy—as encouraged by the OECD and UNEP—will be necessary to ensure that secondary material use becomes not only environmentally sustainable but also economically competitive at the global scale (OECD, 2020; UNEP, 2021). For the construction sector in particular, this alignment ensures that materials harvested through deconstruction can compete fairly with virgin materials, reinforcing Europe's commitment to reducing the 35% of EU waste generated by construction and demolition activities (EEA, 2021).

Conclusion

In this task 6.3 we have given further notice to the impact of law and economics in the field of sustainability and a circular economy for building materials. In our analysis we emphasize the role of well-defined property rights with the help of blockchain based UUID or Unique Object Identifiers to materials in building to challenge the obstacles for a circular economy.

Showing that well defined property rights, including aspects of liability and transparency, can also solve not only sustainability issues, but also provides us a broader framework for a circular economy in which several issues can be addressed, including the problem of information asymmetry and lacking institutional arrangements in a circular economy, which lead to very low levels of productivity in a circular building economy.

The combination of Law and Economics, resulting for a circular economy in the issue of well-defined property right makes it possible to connect the real world of a brick with the future transaction of this brick into a new purpose. Without losing the materials and without the need to produce new materials. Law connects the value of this brick with the finance of the future use of the brick, including the ability to keep the value of the brick alive (economics).

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APPENDICES

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LIST OF APPENDICES

APPENDIX A The Circular Demolition Handbook

This appendix presents *The Circular Demolition Handbook*, which forms the basis for the research activities and findings reported in Task T1.4, T6.2 and T6.3 of SUM4Re. Throughout this report, references are made to specific chapters and sections of the Handbook. For SUM4Re, these relevant parts have been highlighted with dedicated markers and annotations.

The Handbook continuously evolves by integrating new research results, lessons learned from pilot projects, and contributions from related initiatives, making it not only a supporting document but also a circular product in itself.

Circulair Demolition
HANDBOOK

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MAY 2025

Circular Demolition Manual

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May 2025
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Erol Oztan: Block Materials
Tomas de Preter: Leap Forward
Ambre Reijntjens: The Innovation Tree
Michiel Ritzen: Vito
Eléonore de Roissart: Buildwise
Rizal Sebastian: The Hague University of Applied Sciences
Camille Simon: Greenflex
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Laurens Somers: Leap Forward
Rob Stefens: Dynabloqs
Emil Stoyanov: Recheck
Bram Tankink: Brightlands Chemelot Campus
Joep Versteegen: Block Materials
Toon Versteegen: Block Materials
Jeroen Vrijders: Buildwise
Ida Weber: Brightlands Smart Services Campus

CONTENTS

SUBJECT GUIDE

If you want to quickly find out more about a specific part of the entire chain of Circular Demolition, use the subject guide below. For many subjects, the table below indicates which part, chapter or paragraph can be consulted for this subject. Do not forget that true Circularity concerns understanding the entire chain of Demolition. However, it often starts with a link. This table will be updated at the end of the writing process of this third version.

How should I read this manual?

To support the implementation of various projects within European and Regional Circular Construction and Demolition programmes, a Handbook has been drawn up since 2019 with the start of the project **Digital Deconstruction**.

This third edition of the Handbook has been updated from an earlier version with:

- insights from the European project **CircularB**.
- the results of the **Demo Blog** project
- the objectives and first results of the SUM-4RE project
- the results of the preparation of the **National Growth Fund** application for Building Passports
- the insights from the start-up phase of the **European Centre for Circular Building and Transformation** (ECCBT).

Many of the previously created documents, texts, plans, diagrams and ideas fit into a manual, and have previously been developed in the perspective of the property or project owner. A perspective that is extended in this third version with other target groups, such as the architect, the construction company, the demolition company, the inventory of materials or the support for the various projects in the field of Circular Construction and Demolition.

In particular, the SUM4RE project ensures that additional attention is paid to the labour productivity of the inventory process of buildings, the **National Growth Fund** with regard to the macro-economic conditions for the development of a Circular Economy in Construction, and Demo-Blog on the (behavioural) perspective of architects and construction companies with regard to a marketplace for secondary materials.

Nevertheless, in this version of the Handbook, the real estate owner remains the basic stakeholder. By taking this stakeholders as the basis for the manual, not only is the perspective of a building object and its owner the focal point of our analysis, but all process components can also be linked to decision-making questions for a real estate owner. Even if he or she needs help an architect, construction company, demolition company or inventory expert. In other words, the sum of all decision-making questions for the real estate owner also provides the integral interpretation of the cost-benefit analysis that every real estate owner has to deal with. The other target groups are part of this process, but it is ultimately at the level of the real estate owner that all the lines come together.

An important perspective, also for other user groups, because in Circular Construction and Demolition it is actually the owner of a building who makes the final decision on how to deal with his or her property. This does not have to be just a building, but can also relate to the materials that are present in a building, or are removed from a building. That either belonged to the owner of the building, or have remained the property of a supplier of these materials.

The process components in each chapter can be seen as the beginning of the script for each project owner or supporting stakeholder. Examples of projects and cases will be described at the beginning of this manual, because bridging the gap between the practical aspects of Circular Demolition and reuse of materials on the one hand and various scientific and theoretical insights with regard to Circular Construction and Demolition on the other, is a main challenge. A gap that is wide open, but for which attention is actually increasing, partly caused by sharply rising material and energy prices. Which makes reusing materials from a environmental, economic and geo-political perspective a broad challenge for many parties.

The Handbook will also be able to serve as a guide for change, because Circular Demolition or **Digital Deconstruction** is about how things around the construction, use and removal of buildings and materials can be changed. From a classic way of building and deconstructing building to a circular way. Where are the possibilities for behavioral change and who are the *“stakeholders”* where this is possible?

So far, experiences in projects and cases show that the architect and the construction company are weak links in the change process. The property owner is a strong link, but is characterized by a lack of knowledge. Also, the labor productivity of each stakeholder in a circular economy is relatively low. Insights for improving this labour productivity will therefore be continuously addressed from the SUM4RE project, where this is also the case in the various processes of circular demolition.

However, in everything, the construction consultant is the knowledge link between all parties and this person must be able to be trained, partly based on examples and projects in which the construction consultant himself is responsible. Projects in which there is an ongoing cost-benefit analysis because the industry and the entire chain of companies and organisations that deal with construction materials are cost-driven, and therefore often make decisions for a short term. Circular Construction and Demolition is, however, primarily value-driven. Values in terms of the physical side of a material, which must be able to remain in place, value in material terms, in the sense that a material must be able to fulfil the highest possible function in society, and value-driven in terms of the environment, where the use of materials must not be at the expense of our living environment and nature.

This requires the necessity to make the value of materials transparent, and that this value must also be able to flow back to the owner. The construction consultant must be able to make this analysis and draw up requests for quotations to demolition/dismantling companies, logistics and construction companies to provide services, whereby the materials remain with the original owner and are not taken away by the demolition or construction company, other than against payment of the highest possible value of the materials in social traffic. A major challenge.

Activities for which this Handbook will be of great use!

Questions are open for answering in each chapter, as are comments on what is currently being expressed in each chapter in the handbook. Scientific and project references are being added to the various versions on an ongoing basis.

A Handbook is a large document. If you are looking for specific parts, use the *“Subject Guide”* that is included after this introduction.

Suggestions for improvement are more than welcome!

Simon Duindam

Heerlen/Melbourne/Bergen (No), Juli 2025

Part 1

General Vision, Challenges and Objective From the Manual For the Property Owner

1. THE BASIS OF THE MANUAL

The general vision behind the Manual's quality framework.

The basis of the Manual lies in the daily experiences of the real estate owner - pilot owner about the quality of the various demolition processes of his or her real estate. Quality is therefore formed by extracting from these daily experiences those experiences that are truly shared with each other and are considered 'good' or 'the best'. And can therefore also be used frequently in the daily activities of the real estate owner, as a reference for a new demolition plan to be made or adjusted.

Quality within the manual is therefore primarily not formed by standards for production, legal requirements, professional registrations, etc. Even though requirements from governments, suppliers, own organization, residents, and other stakeholders impose boundary conditions that must be considered. These are the boundary conditions, but not the heart of the Circular Construction and Demolition Manual.

Process component

The Property Owner's Manual is the result of a working method of the Users, in which, based on daily experiences and with the help of all kinds of support documents, instruments, methods and techniques, the following processes of the Property Owner - Pilot Owner are supported:

1. Preparation of all activities
2. Making a qualitative cost-benefit analysis of the demolition method of a building.
3. Inventory of the materials present in a building and registering these materials in a digital materials database.
4. Granting rights to materials.
5. The assessment of social values of the reusable materials in a building.
6. An inventory of the costs of services related to the desired demolition of the building.
7. Completion of the qualitative and quantitative cost-benefit analysis and decision-making on the method of demolition of a building.
8. Preparation for demolition.
9. Conducting the demolition and securing the value of the materials in the building.
10. Securing the materials for physical reuse in a depot, including an overview of available materials for the architect and construction company.
11. Processing of materials.
12. Organizing the physical reuse by trading the materials in an internal or external marketplace.

The Manual describes the details of the processes and the associated documents, experiences, questions, and answers for each part of the process. This also results in a template for the property owner - project owner for each process part, with which each process part can be filled in. A practical script for every sustainable demolition project.

Chapter 1: Preparation of all activities

Chapter 2: Creating a qualitative cost-benefit analysis.

Chapter 3: Inventory and registration of materials.

Chapter 4: The transfer of rights to materials.

Chapter 5: Social valuation of reusable materials.

Chapter 6: Inventory of the costs of services during the demolition of a building.

Chapter 7: Decision making.

Chapter 8: Preparation for demolition.

Chapter 9: The execution of the demolition and the securing of the value of the materials.

Chapter 10: Securing the materials in a depot.

Chapter 11: Processing.

Chapter 12: Marketplaces.

Classification

For each process component of the Manual, a fixed classification is used. Each category in the process gives content to a component of the process, or makes a connection with another process component, or indicates which sources have been used to colour the content of the process component. The categories are the following:

1. **Introduction:** a brief description of this process component and the goal to be achieved in this component.
2. **Input:** a description of what resources or previous results from other process components are needed to further develop this component.
3. **Products and services:** A description of the products or services that can be achieved by elaborating this process component.
4. **Methods ,Techniques, Templates, and Instruments:** an elaboration or clarification of the tools (methods & techniques, templates, and instruments) used in this process component to ralize the products and services.
5. **Results:** A description of the results achieved through the products and services in this process component.
6. **Quality factors:** a description of the various aspects of quality that are addressed in this process component.
7. **Process activities:** description of the activities that are or have been involved in this process.
8. **Questions and Answers:** A description of all questions and answers for this process component.
9. **Comments:** a list of the comments and experiences discussed in this process component, including any reflections.
10. **References:** an overview of sources and (scientific) references used when describing this process component in the manual.

The Manual also represents the collective memory of the partners of all projects that feed into this manual, whereby a *"paper"* version is initially used, and this can later evolve into a version that can be accessed using a knowledge base.

To help everyone with that collective memory in their daily work, it is therefore important that experiences are shared. That these experiences are provided with insights, and that these insights can also be returned to all participants of a project via an electronic knowledge system, by participating in additional workshops for all members and by participating in learning circles. In this way, every participant also knows what is good, which could save a lot of puzzling and searching time in daily work.

1. 1. PROJECTS AND CASES

A large amount of information has been collected for the manual on projects and cases that are working with Circular Demolition. These are primary sources, which the Manual team is working with directly, and important secondary sources of projects in which experiences and examples are discussed that are important to share for the realization of a regional sector Circular Construction and Demolition.

The primary sources come from the following projects:

1. **Digital Deconstruction**
2. Activities Manual Circular Construction and Demolition in Parkstad Limburg
3. **Demo Blog**
4. **SUM4Re**
5. Application for **National Growth Fund** Building Passports
6. **European Centre for Circular Building and Transformation**
7. Circular B

The secondary sources come from the following projects:

1. Regional Innovation Hubs within **Digital Deconstruction**
2. European project reports
3. Experiences and reports from stakeholders within the **European Centre for Circular Building and Transformation**
4. Professional literature

We will briefly describe each project on the table below. In the reflections and references for each chapter in this manual, we will then make a connection with the projects. In doing so, we will show for each component which aspects of a project give substance to the necessary practical aspects of Circular Construction and Demolition for that component. The table below will be updated at the end of the writing process.

Primary sources:

	Name	Owner	Sector	Sort of Building	Type	Location
1	Housing association homes	Vilogia	Housing	16 homes	Demolition	Lomme – France
2	Gare Villeneuve Saint George	SNCF/AREP	Station	Station building	Renovation	Villeneuve Saint George – France
3	Hof ter Laken	Kempens Landschap	Monument	Castle	Demolition	Heist-op-den-Berg – Belgium
4	School Berlaar	Kempens Landschap	Education	School building	Demolition	Berlaar – Belgium
5	Heerlen City Hall	Gemeente Heerlen	Government	Office building	Demolition	Heerlen – Netherlands
6	Thermen Museum	Gemeente Heerlen	Museums	Museum	Renovation	Heerlen – Netherlands
7	Ettelbrück Station	CFL	Station	Station building	Demolition	Ettelbrück – Luxembourg
8	Promenade	Gemeente Heerlen	Public space	Square/Street	Renovation	Heerlen – Netherlands
9	Brightlands Office	Brightlands Chemelot	Industry	Office building	New construction	Geleen – Netherlands
10	Processing Plant	Renewi	Industry	Industrial complex	Processing	Eindhoven – Netherlands
11	DreamHûs	TU Delft	Education	3 homes	Transformation	Delft – The Netherlands
12	Boerderij	City of Turnhout	Government	Industrial complex	Demolition	Turnhout – Belgium
13	DSM-building	Wonen Limburg	Office	Office building	Renovation	Heerlen – The Netherlands
14	Binckhorst	City of The Hague	Industry	Industrial complex	Demolition	The Hague – The Netherlands
15	Longyearbyen	City of Longyearbyen	Residential	Appartment Complex	Renovation	Svalbard – Norway
16	Jolastokieta	Cityo of San Sebastian	Industry	Industrial complex	Demolition	San Sebastian – Spain

Secondary sources:

	Name	Owner	Sector	Sort of Building	Type	Location
1	Croix Luizet	Est Metropole Habitat	Home	100 housing units	Demolition	Villeurbanne, Lyon – France
2	1 Triton Square	British Land	Services	Office building	Renovation	London – Great Britain
3	80 Charlotte Street	Derwent	Mixed	Mixed construction	Refurbish	London – Great Britain
4	JLL Office Fit-out	JLL	Services	Office building	Renovation	Manchester – Great Britain
5	Roots in the Sky	Fabrix	Services	Office building	New construction	London – Great Britain
6	Holbein Gardens	Grosvenor	Services	Office building	Refurbish	London – Great Britain
7	The Forge	Landsec	Services	Office building	New construction	London – Great Britain
8	Blackrock Street	One Manchester	Home	Houses	New construction	Manchester – Great Britain
9	Het Enterprise Centre	University of East Anglia	Education	School building	New construction	Norwich – Great Britain
10	Cambridge Avenue	SEGRO	Logistics	Shed	Reconstruction	Slough – Great Britain
11	Het Entopia-gebouw	Cambridge Institute for Sustainability Le	Education	School building	Renovation	Cambridge – Great Britain
12	Timber Square	Landsec	Mixed	Office and shop	Renovation	London – Great Britain
13	The Burrell Collection	Gemeente Glasgow	Museums	Museum	Renovation	Glasgow – Great Britain
14	Canal Reach	Bennett Associates	Services	Office building	New construction	London – Great Britain

2. Circular Construction and Demolition: an outline of the situation in 2025

2. 1. What is a Circular Economy?

The Ellen MacArthur Foundation defines a circular economy as:

> The circular economy is a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting. The circular economy tackles climate change and other global challenges, like biodiversity loss, waste, and pollution, by decoupling economic activity from the consumption of finite resources.
>
> The circular economy is based on three principles, driven by design:
>
> - Eliminate waste and pollution,
> - Circulate products and materials (at their highest value) and
> - Regenerating nature.

The world population is constantly growing and is faced with new needs for new constructions and buildings. This puts enormous pressure on our environment and resources. The construction sector is responsible for approximately 33% of greenhouse gas emissions, 40% of waste generation and 40% of material consumption (Hossain & Ng, 2018; Ness & Xing, 2017).

In 2020, the European Union adopted a new Circular Economy Action Plan (CEAP) with more concrete measures to reduce pressure on natural resources and create sustainable development. Circular Economy (CE) Action Plans involve gradually decoupling economic activity from consuming finite resources and designing a second life for waste. Circular models play a key role in this.

A circular model distinguishes between technical and biological cycles, where:

1. Biologically based materials and building components in general are designed to feedback and regenerate living systems.
2. While engineering cycles recover and restore products, components, and materials through strategies such as reuse, repair, remanufacturing or (as a last resort) recycling.

The application of CE principles in real estate, building design and use (adaptability, sustainability, waste reduction and high-quality management according to the European Commission (EC, 2020)) is mainly focused on new construction where circularity can be embedded and facilitated from the early design phase and thus throughout the entire life cycle of a building and its components and materials.

> Conversely, circularity in the context of existing buildings has not been defined so far (Kyrö, 2020). The multitude of definitions of CE, and more specifically circularity in the built environment, does not contribute to a coherent, systematic approach. CE should be seen as a business strategy, not just as waste management, or a design strategy.

In response, several principles have been developed that relate to Circular Construction and Demolition. The figure below, taken from the UK Green Building Council report, Insights on how circular economy principles can impact carbon and value (August 2022), illustrates these five principles in more detail. The report, which was primarily written with a focus on reducing CO_2, is also a practical guideline for preventing material loss during the demolition and renovation of buildings, due to the direct connection between the reuse of materials and the reduction of CO_2 by preventing new production of materials.

Precisely because this Manual contains various practical tools for Circular Building and Deconstruction, it is good to reflect on these five principles. In the remainder of the Manual, we will therefore also be able to refer to these five principles and, where possible, to the Key Drivers below for the use of Circularity in Buildings.

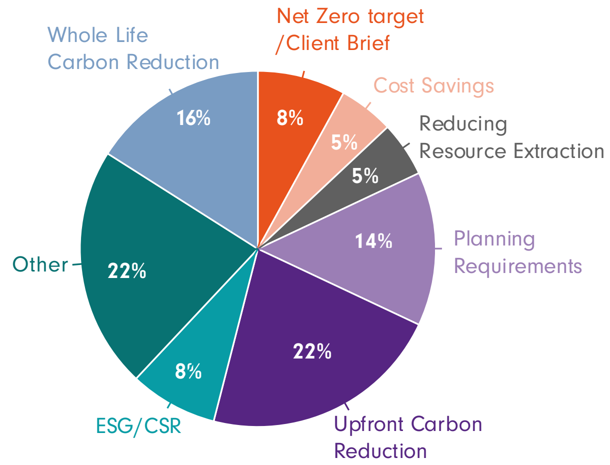
Explanation of the five principles

Principle 1: *Maximize reuse.*

1. **Reuse of the existing building:** Reuse of an entire building, or re-use of a significant part of the existing building, to meet similar or unique needs and/or uses (e.g., from industrial to mixed use) while exceeding current regulations and standards through restoration or major alterations.
2. **Reclaiming materials on-site or off-site:** Incorporating reuse elements and materials reclaimed from the existing site or off-site into the new development.
3. **Sharing materials or products for further reuse:** Where materials and products cannot be reused on site, they are sent for further reuse via a broker or back to the material supplier for refurbishment, reuse, or recycling (as a last resort).

Principle 2: *Design for Optimization*

1. **Design for longevity:** Create a building with well-defined long-term needs, which is sustainable, resilient, and able to cope with social and environmental change. It requires little modification/no replacement of components, because of its 'loose fit', generous proportions and openness to alternative technologies.
2. **Design for flexibility:** Balance the needs of the present with how those needs will change in the future. Enable change



through frequent reconfiguration, including reconfiguration of non-structural components—configurations are likely to be agreed in advance with planning and building management and do not involve *"wet trades"* or waste.

3. **Design for optimum adaptability in a building:** meeting the needs of the present but considering how those needs may change in the future, allowing for change in the form of periodic renovation.
4. **Design for assembly, disassembly and repairability:** Products and services are designed to be partially assembled, deconstructed, and reused or recycled.

Principle 3: *Use standardization.*

Designing and constructing buildings that use standardized elements or modular designs for materials and products that allow for a reduction in construction waste and easier reuse in the next life. Standardization combined with off-site methods that reduce waste can reduce upfront carbon. However, standardization in design could increase carbon if not applied carefully and strategically. Standardization also has close links to Designing for Deconstruction if the system is designed for easier reuse. There are also links to flexibility and adaptability if the standardized components are designed to be modular and interchangeable, whether these are internal furnishings or structural components.

Principle 4: *Products as a service*

Promote and establish a payment structure that allows customers unlimited access to resources, but only pays for what is used, or for the outcome associated with their use. This means moving from selling products to selling services. Products as a Service (PaaS) have the potential to reduce carbon and material use through efficient maintenance and refurbishment cycles, as well as take-back programs that focus on preventing waste and recovering or adapting products for future use.

Principle 5: *Minimize impact and waste.*

1. **Use new low-impact materials:** All new materials specified in the development are low-impact materials that have little or no adverse effects on the environment or human health throughout their life cycle.
2. **Use recycled content or secondary materials:** Recognize and encourage the use of recycled content and secondary aggregates, thereby reducing the demand for virgin material and optimizing material efficiency in construction.
3. **Design for waste:** To design for waste throughout the building life cycle so that there is minimal waste during the design, construction, deconstruction, and subsequent life of the built asset. While designing for waste is critical, it should be noted that when designing for future adaptability and flexibility, it is possible for the structure to be over-specified to support additional loads in the future.
4. **Reduce construction impact:** Ensure that construction sites reduce on-site waste, including packaging. Low impact materials identified in the case studies did not result in higher initial carbon emissions. However, the full LCA of low impact materials should be considered to ensure that there are no unintended carbon impacts due to frequent replacement or renovation cycles. Using low impact materials may result in buildings having a lower LCA than renovating the existing building.

2. 2. CHALLENGES FOR THE CIRCULAR ECONOMY IN EXISTING BUILDINGS.

Existing frameworks to implement and assess circularity suffer from a mismatch between supply and need. There is an oversupply of theoretical guidelines and tools that illustrate the basic principles of CE in buildings. Yet, most tools have the same goal, while there is a need for practical evidence on the usefulness of these tools and their impact on the design process to highlight best practices.

With very few examples of implementing CE in practice, the practical transformation from a linear business model to a circular model for Construction and Demolition is still the main (research) gap in terms of consolidated circular practices that guide all companies and organisations towards improving the circularity of their products or services and stimulating policies to subsidise.

Below are some of the challenges related to the above gap, which we aim to mitigate through the content and guidelines of the manual.

1. To fully benefit from the implementation of circular strategies, supply chain management and monitoring over time should be essential. This includes ensuring an efficient flow of information between stakeholders (Cambier et al., 2020). In this regard, the need for matchmaking tools emerges to connect verified stakeholders. A smooth process also calls for legal support and guiding policies to ensure compliance with circular strategies.
2. The implementation of circularity strategies in the construction and real estate sectors is still hampered by the lack of innovative business models that ensure implementation without compromising economic viability and value capture by market players.
3. Reclaimed materials from existing buildings face a critical barrier in their technical compatibility and quality assessment, questioning their direct reuse. This leads to downcycling processes, attracting additional resources and energy flows.
4. Several tools have been developed for Circular Demolition to support decision-making on the design and/or assessment of

buildings for circularity. Most tools have been developed to focus on specific aspects of circularity without considering other aspects, such as supporting product and material selection by only substantiating material-related indicators based on their environmental impacts.

5. The available tools fail to address a comprehensive conception of circularity and lead to a loss of critical capacity when used in isolation, as they do not assess all other important design aspects, e.g., building composition and connectivity between elements, durability, and lifespan of building components. This is because circularity values arise when specified intrinsic properties (material and product properties) intersect with relational properties (building design and usage properties) (Geldermans, 2016). For example, a building may be made of 100% circular materials and products, but when these are inaccessible for replacement or maintenance, the building system becomes non-circular. This also applies to the barriers or ambiguities that arise as time pass and information about a building or the material in a building is no longer up-to-date, or because there is no incentive to keep them up to date.
6. In the spectrum of the Circular Economy, more recent tools have been developed, such as Circular Building Assessment Prototype (CBA) developed by the European Union (EU) project BAMB, Circularity Calculator (IDEAL&CO, 2021) and Building Circularity Index (Alba Concepts, 2021). These tools introduce rating systems to calculate a circularity score with the aim of objectifying the circularity performance of a building or a building element. However, they are criticized for their lack of a participatory and practice-oriented approach, fundamental to the need to assess the impact of assessment tools on the design process. Moreover, there is no clear link between the outcome of these tools and the actual environmental impact of the solution studied.
7. The challenges in identifying impacts of circular economic actions:
   a. Circular design principles are rarely applied in silos. Only in connection with the integral chains in an ecosystem of a circular economy does this take place, because then a future and value perspective are also generated where this is relevant.
   b. Circularity and non-financial value are not measured consistently.
   c. Inconsistent carbon assessments in life cycle assessment.
   d. Carbon Assessments (life cycle) are not yet the norm.
8. An integrated, interdisciplinary and transdisciplinary approach to CE implementation and assessment in the construction and real estate sectors is needed for Circular Construction and Demolition. This can be achieved by ensuring that circularity is implemented in all related activities and value chain management, while reconciling its integration with other factors in sustainability frameworks. Until now, the implementation of CE principles in building design and management has been limited to the application of individual strategies addressing certain aspects of circularity, for example the development of circular materials.
9. However, a circular construction approach is not limited to material circularity. It transcends individual aspects of the dynamic total of all processes that enable a circular flow of these materials and products, including planning, management, design, operation, maintenance, and end-of-life aspects. Considering all value chain factors and policies that support implementation and economic value creation.

The EU-COST programme **CircularB** works with a holistic framework for circularity to create, assess and benchmark buildings taking into account all stages of the life cycle, from planning to end-of-life options with all associated input-output flows of materials, as well as the involvement of a diverse group of stakeholders with interlocking specialities.

Where possible, we will refer to the questions raised by the holistic, integrated approach advocated in the **CircularB** programme in the references in the Manual. These sections of the Manual will therefore refer to these twelve questions. The principles of a Circular Economy, as discussed at the beginning of this chapter, will also be presented where relevant. Principles that can also serve as standards for a (regional) government, for example, to encourage other stakeholders in the ecosystem of a Circular Economy, or to strengthen the connection between the various pillars of an ecosystem for a circular economy.

The new projects **Demo Blog** and **SUM4Re** tie in with the above questions and can also provide a (partial) answer. About the use of Building Passports or Building Logbooks, **Demo Blog** concerns questions 2, 7, 9, 11 and 12. For **SUM4Re**, The questions 1, 2, 3, 4, 5, 8, 9, 11 and 12. are relevant

Within this context, this COST action will attempt to answer the following research questions.

1. How can circularity be defined as a complex property in buildings?
2. How can the principles of circularity be integrated into all phases of a building's life cycle, from concept to end of life, considering all components, products, and systems already during the design of new buildings and larger renovation projects?
3. What are the drivers and barriers for the integration of circularity strategies in buildings for COST countries and beyond at the different levels? Have best practices been identified?
4. Given that existing circularity indicators and assessment frameworks are not sufficient to provide a holistic approach to the implementation of circularity in buildings, what are the other complementary aspects that are still missing, taking into account all technical, technological, economic, environmental, legal and social factors? How can they be brought together in one inclusive model? Is there a possibility to express circularity as a complex characteristic in one indicator or index or is there a need for a set of indicators?
5. Is it possible to quantify the circularity potential of a building, considering, among other things, emerging opportunities for disassembly, adaptability, deconstruction, reuse, and sustainability?
6. Does circularity contribute to sustainability? What is the relationship between sustainability as an overarching goal and circularity as a sub-strategy to support more sustainable development?
7. How to assess the benefits and sustainability of circularity measures? Are there trade-off's?
8. How can the stakeholders within the quadruple helix contribute to the realisation of circular construction? What is their respective role in realising a circular value chain? And what incentives are needed to make their roles more efficient?
9. What strategies and tools need to be developed to enable transformation along the entire value chain?
10. Are there additional requirements for the design and development of new (next generation) products?
11. How will circularity contribute to the availability of secondary materials?
12. What new business models are there – from leasing systems to take-back options?

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PART 2

THE REAL ESTATE OWNER PROJECT OWNER

1.

PREPARATION OF ALL ACTIVITIES

The result of all the preparatory work is the availability of expertise in the field of inventory, project management and cost-benefit analysis.

And its processes around information and research, training, facilities, expectations and the possibilities of reusing materials

1. 1. INTRODUCTION

In order to make a good analysis of the future of a building and to reuse the materials present in the building in a high-quality way, this manual offers structured access to a large number of instruments that can be used in different steps. In order to use these instruments, as well as methods and techniques correctly, the user of the manual must have a good overview. For this, it is desirable that all activities that have to do with the reuse of materials in a building are well prepared. This is also because of the desire to be able to work as holistically as possible. It also promotes the issues and challenges to increase labor productivity in the different parts of a circular economy.

This chapter indicates which preparatory activities are desirable. The description of these activities also addresses the scope and quality of these preparatory activities.

1. 2. INPUT

The following elements can be mentioned as input for good preparation:

1. Access to this manual
2. Access to 3D scanning expertise
3. Access to expertise regarding removability/RBIM expertise
4. Access to the Digital Materials Database Cirdax (integrated with marketplaces and marketplace tools)
5. Access to templates for a (social) cost-benefit analysis
6. Access to drawings and other information sources relating to a building
7. Access to sufficient space on servers
8. Access to general expertise/process control related to performing a material reusability analysis and the demolition and/or dismantling of a building
9. Access to a list of potential buyers

1. 3. PRODUCTS AND SERVICES

No specific products or services are used in this part of the process, other than the services of a project manager.

1. 4. METHODS, TECHNIQUES, TEMPLATES AND INSTRUMENTS

Methods and templates for setting up a project. It is desirable to have a form or application that indicates whether all components of a preparation are actually present.

1. Template Plan of Approach Circular Demolition Projects
2. Template Project Plan Circular Demolition Projects
3. Checklist of instruments that have already proven their value in a specific context

1. 5. RESULTS

The result of all the preparatory work is the availability of the capabilities and expertise in the field of inventory, project management, cost-benefit analysis and access to the right tools with which a material reuse process can be set up for a specific real estate object.

1. 6. QUALITY FACTORS

The hired expertise must provide the capacity and knowledge to execute a project in the field of reuse of materials in a building. If necessary, a project manager or consultant must be trained in the use of tools and templates. A project manager must be able to execute the activities mentioned in the manual in relation to a specific project. He or she must also be able to operate all the mentioned tools, or manage and understand the hired expertise. The final competence test of the project manager in question is the first delivery of an analysis on the reuse of the materials, as well as the actual delivery of the reusable materials to a depot, purchaser or to a new customer.

1. 7. PROCESS ACTIVITIES

Below are some examples of process activities in the preparation phase. The examples from France and the project **Digital Deconstruction** are relevant for many projects, because in France there is an obligation to make a material inventory before a building is actually demolished or dismantled.

1. About information and research

- Search and consult sources that collect information (for example in France: materiauxremploi.com, BAZED, Circolab, etc.).
- Search and consult approved accompanying documents (for example in France: REPAR, Guides FBE, Circolab, etc.)
- Provide extra time for studies (general).
- Be precise in the terminology used in the documents. Adding a glossary to the tender is an example of this.
- Use guidelines or existing specifications and templates for a concept tender (e.g. in France: Circolab document, etc.)
- Provide access to as much existing information about the building as possible.
- Research different typologies of actors: potential building owners interested in reuse for their projects, specialised deconstruction-demolition companies, social enterprises proposing specific works (temporary recovery of products, stock, treatment, commercialisation, reuse), associations, experimental designers, industrial and construction companies able to integrate reused/recycled materials, physical and online marketplaces.

2. About expertise and training

- Identify and contact a building owner and/or architect and/or design firm, ideally on the project site, who has experience with reuse approaches. They can provide you with targeted stakeholder contacts, sources of information, tips and experiences.
- Organize or receive a dedicated training session. Specialized actors propose training sessions based on experience and accepted methodologies for reuse approaches (for example in France: Bellastock, IDRE, Nobatek/Inef4, etc.)
- Make employees aware of the project in terms of context/vocabulary/needs for deconstruction and reuse approach.
- Ensure an exchange with local partners who have already implemented circular projects.
- Make sure that all stakeholders understand each other, speak the same language and that the program is really understood. You can also propose a glossary that all employees can use.
- Identify the existence of local parties that are able to deconstruct elements, support the project, store, treat and reuse materials. It can influence the feasibility of the wishes of a property owner, especially if there is a guaranteed offtake of materials that are released from a building and will therefore also be reused at a relatively high value.
- If you do not have the competences internally, find an experienced agency to handle the project and integrate as early as possible. Ideally, this support agency should be local in order to know the local context well.
- Find an experienced inspection agency in the field of deconstruction and reuse. Integrate them as early as possible in the process. Again, this saves/gains time, which can be beneficial later on. For example, for a correct matching between supplier and requester of materials.
- Provide access to as much existing information about the building (drawings, design documents) as possible to the support office
- Discuss these issues with the support office or project management team as early as possible:
- Is there a local site to store the deconstructed elements before they are sold, reused or upcycled?
- If reuse is on the same site, does the inspection agency have a specific mission regarding reuse?
- In some cases, the building owner has minimal internal knowledge. However, when project management teams (architects + engineering firms) with expertise in Deconstruction and Reuse exist, a support office may not be necessary.

3. About facilities and processes

- Find a storage space near the building being demolished.
- Identify internally, or with a support office, the resources/products that are commonly reused to understand the business model.
- Integrate preparatory deconstruction activities into the follow-up process. Take photos, keep traceability documents.
- Be sure of the safety of the interventions (access, deconstruction).

4. About expectations

- Be realistic, generally do not think about reusing all components of the existing building, but define general expectations and goals. This also includes the possibility of upcycling, because this prevents losses of materials, and possibly achieves higher economic values, than with reuse alone. Upcycling can better meet the current demand for materials.
- Determine if you want/need to reuse the products in situ (in renovation or remodelling). Determine with the owner if a few elements need to be deconstructed for his own needs on other projects
- Clearly articulate the desire for deconstruction and reuse and define this as a critical objective for the project.
- Frame the mission/expectations for the support office. Is it merely an evaluator and facilitator of the project management team, or should it support the design team in designing and implementing the approach?
- Be clear in the tender about the deconstruction and reuse objectives of the project.

5. On the reuse and sale of reusable materials

- Identify potential users/buyers of the products, physical and digital marketplaces by searching the internet (directly or via a website that collects information such as _https://materiauxreemploi.com/, FCRBE, etc.), or by asking for information from local actors_)
- Regarding potential users, instead of a marketplace, you can also contact building owners or housing associations directly. Find information about local building projects, contact local municipalities, social housing owners, identified support offices and architects.
- Communicate on the internet, local events and press, mainly to attract potential parties.
- Where possible, organise site visits and ensure that a person is available to organise specific visits for interested parties.

1. 8. QUESTIONS AND ANSWERS

The following questions and answers can be added to this chapter.

Question: Deconstruction takes longer than demolition and some materials may not be immediately available. This will both increase development costs and reduce short-term rental income.

Answer: Develop a detailed program and life cycle cost analysis and involve contractors early in the process to minimize the risk of delays. In the Entopia building (see project list), contractors were engaged under a pre-construction service agreement.

Question: When products and materials are made for sale, rather than owned by the customer, optimization for future scenarios is typically not undertaken.

Answer: Client teams and designers should be encouraged to think about the future use of assets and one way to do this may be to include annual carbon reporting alongside LCA assessments. Exploit the marketing opportunities of future benefits, including buildings as material banks, such as the BAMB2020 project.

Question: Market tastes are likely to change, and many buildings are not used for their full design life.

Answer: Longevity should not be used as a standalone solution, but instead combined with deconstruction, flexibility, and adaptability. Better community involvement is needed to first prioritize existing buildings and how they can be repurposed for other uses, and where possible involve the end user in decisions to better design for future possibilities.

Question: The start-up costs for tooling on-site production facilities when customers use their own standardized systems.

Answer: This should reduce upfront costs as customers' economies of scale develop. Off-site manufacturing facilities, if customers can guarantee carbon and material savings through standardized methods, will outweigh transportation carbon. On-site facilities can also accelerate construction time, increase local employment, and reduce transportation/construction intensity over time.

1. 9. COMMENTS

The following comments may be added to this chapter.

Comment 1: The desired cycle of circular use of materials currently only exists for a few materials, such as metals. For the other materials, there is no cycle, because after using the materials in a building, most of the materials are dumped, burned, or reused at a low value after demolition (no disassembly). For these materials, it is economically cheaper to buy new materials than to let existing materials undergo the actions of the cycle. However, for more materials, this balance is starting to shift, driven by price increases for new materials, as well as the pricing of the social costs related to the destruction of existing materials. This is done considering liability and CO_2 prices to produce alternative new materials (ETS rights).

Within the **SUM4Re** project, further research will be conducted into the materials wood, concrete, steel beams, reinforced concrete, and asphalt.

Comment 2: Examples of waste processors of building materials show that waste is increasingly becoming a raw material, because after sorting and cleaning the materials, new raw materials are created that are competitive with primary raw materials. The same goes for products.

Not because these secondary raw materials have now really become cheaper, but because the costs of primary raw materials are rising explosively. This creates a business model for the cycle of secondary materials along the path of upcycling, in which inventories of the costs and benefits of actions in this cycle model are of great importance to give as many stakeholders as possible in buildings an integral insight into their own derived revenue model, which often includes part of the entire cycle.

This is in comparison with a classic method of building and demolition, in which the disappearance of materials is an issue.

Comment 3: The following challenges related to Circular Construction and Demolition from the **CircularB**-program, **Demo Blog** and **SUM4Re** programs are related to this chapter of the manual:

- How can the principles of circularity be integrated into all phases of a building's life cycle, from concept to end of life, considering all components, products, and systems already during the design of new buildings and larger renovation projects?
- How can the stakeholders within the quadruple helix contribute to realising circular construction? What is their respective role in realising a circular value chain? And what incentives are needed to make their roles more efficient?
- How can Building Logbooks and the support of stakeholders in using these Logbooks make use of an integral form of support that is integrated into the Logbook. In terms of processes in tasks, projects, and programs and in sharing, securing, and consulting knowledge and competences.
- What does an integrated way of working and supporting mean for the labor productivity of all stakeholders in a Circular Economy?

1. 10. REFERENCES

No references have been added to this chapter yet.

2.

CREATING A QUALITATIVE COST-BENEFIT ANALYSIS

The activities leading to a qualitative cost-benefit analysis concerning reusing materials are:

- An overview of all costs that can be included in a cost-benefit analysis.
- An overview of all benefits that can be con sidered in a cost-benefit analysis.
- How the factors of time and quality should be dealt with in a cost-benefit analysis

When preparing a cost-benefit analysis the following analytical activities are involved:

- The removal costs of materials from a building
- The alternative returns are available and the value of the returns
- The role of detailed and qualified information
- The combined legal, economic, and technological aspects that ensure that the reuse of materials is guaranteed over time.
- Calculating processing or repair costs for a primary quality.

2. 1. INTRODUCTION

In the 1937 article *"The Theory of the Firm"*, Ronald Coase called on everyone to investigate the transaction costs of a firm in its relations with customers, suppliers, employees, and organization. In this way, to make a comparison with the costs of individual contracts that everyone can arrange with each other for every transaction that they make. For example, for every hour of work instead of a long-term employment contract, etc. And to tackle this case by case.

The comparison between a classic method of demolition and circular demolition raises a similar thought. Let us compare all (transaction) costs of both alternatives and compare them per pilot or case. So that, based on an analysis of these differences, it can also be determined what causes these differences and with which investments, forms of regulation, the various costs and benefits can be displayed in such a way that Circular Construction and Demolition clearly has added value.

The pilots within the projects **Digital Deconstruction**, **Demo Blog** and **SUM4Re** provide the basis for this. As well as the various figures that can provide insight into the costs and benefits for each part of the circular demolition process. Every decision by the owner of a property to do something with this property is made based on an analysis of the existing and desired situation with the property. This also applies to the demolition of the property or the extension of the lifespan of a property. The analysis of what to do with a property lists various considerations, whereby an overview is made of the various costs and the numerous benefits. These costs and benefits can be expressed in both social and financial terms. The relationship between costs and benefits is also called labor productivity, whereby the various values that can be created with each unit of effort of an employee (labor and costs) are made visible.

In this chapter of the manual, the different types of costs and benefits are first listed, to provide these costs and benefits later with a quantitative value. The experience with demolition and reuse of materials in buildings shows that many decisions regarding the alternative destination of a real estate object are made on incomplete and asymmetrical information. Moreover, the economic and therefore also the physical value of materials is currently in-

An important central objective in the **SUM4Re** project is to investigate methods, techniques, and instruments for their labour productivity. They help us to Provide the information about a building and its materials transparent faster and better than is currently done based on a manual inventory. Improving labour productivity can be achieved by four types of interventions:

1. Increasing the competences of employees. Both about their own possibilities to map buildings and materials manually, and training them in instruments, techniques, and methods (from **SUM4Re**) with which buildings and materials are mapped.
2. Preventing market inefficiencies. This intervention means that activities are performed that allow supply and demand for goods and services to better reach each other. In a circular economy and **SUM4Re** of significant importance, given the issue of information asymmetry between sellers and buyers of materials about the quality of materials. If the quality is known, secondary materials have a high value, if it is not known, it is much lower.
3. Innovation. By using modern technologies and instruments, The manual inventory of buildings and materials can be replaced, or reorganized, whereby routine tasks are replaced by more complex tasks that require the use of people. It creates space for people to perform more profitable tasks with higher labor productivity. We will elaborate on this in chapter 3 using the various instruments that are central to the **SUM4Re** project.
4. Improving the institutions that everyone in society uses. This is not explicitly addressed directly in **SUM4Re**, but it does play an important underlying role. For example, recording the ownership of a material in the blockchain by linking a blockchain registration code to a material passport provides the possibility to always track and use this ownership. It also makes it much easier to perform transactions with these materials, even if they are still present in a building. We will therefore explore further this element of time in this chapter.

sufficiently secured, because of which various benefits are underestimated, and value-driven approaches are insufficiently used.

This chapter therefore aims to list the several types of information that provide insight into both the costs and benefits of the alternative use of a property, as a source of reusable materials. In the subsequent chapters, the various qualitative elements of a cost-benefit analysis are then provided with quantitative data.

2. 2. INPUT

To organize a qualitative cost-benefit analysis, the following input variables are needed:

1. An overview of the available materials in a building
2. An overview of the alternative applicability of these materials
3. An overview of the economic value of materials that can be reused
4. An overview of the social benefits of reusing materials - An overview of other revenues associated with the demolition of a building
5. An overview of the costs of inventory, transparency and alternative material use in a building.
6. An overview of the costs of removing materials from a building
7. An overview of the costs of making the quality of materials in a building or the removed materials transparent
8. An overview of the costs of storage and processing. This also includes the costs that are necessary to restore the quality of secondary materials in such a way that they can be seen as a fully-fledged replacement for new materials. And thus, also taken without problems
9. An overview of the time of a project, so that information about materials is available in a timely manner for the matching process of supply and demand with specific customers

2. 3. PRODUCTS AND SERVICES

A qualitative cost-benefit analysis leads to an overview of the various costs associated with the analysis of the alternative use of a real estate object and the various and associated benefits. In addition, a qualitative cost-benefit analysis leads to insights into the benefits of certain materials if the materials are of good quality and can also be matched with buyers of these materials.

2. 4. METHODS, TECHNIQUES, TEMPLATES AND INSTRUMENTS

To create a qualitative cost-benefit analysis, the following templates and tools can be used:

- Excel form with cost variables
- Excel form with revenue variables

A Materials Database, such as Cirdax or Concular can be seen as a supporting system to make cost-benefit analyses for reuse of materials, because it should be able to store all the information about these analyses, or by providing statistical data resulting from previous inventories and analyses. This latter functionality can only be applied if there is sufficient data about such stocks. Until this goal is achieved, the Materials Database gives us data about the materials in a building, which can be used as a semi-finished product in the cost-benefit analysis. Another semi-finished product is a clear methodology for the calculations behind a cost-benefit analysis.

2. 5. RESULTS

The activities leading to a qualitative cost-benefit analysis provide the following results:

1. An overview of all costs that can be included in a cost-benefit analysis.
2. An overview of all benefits that can be considered in a cost-benefit analysis.
3. How the factors of time and quality should be dealt with in a cost-benefit analysis.

2. 6. QUALITY FACTORS

In a qualitative cost-benefit analysis the following quality factors are addressed:

1. The existing quality of materials present in a building, as part of its identity.
2. The extent to which the removability of materials hinders or enhances the quality of the materials.
3. The extent to which an owner of materials can be held liable for the quality of the materials.

2. 7. PROCESS ACTIVITIES

When preparing a cost-benefit analysis, the following process activities are involved:

1. Analyzing the costs associated with removing materials from a building.
2. Analyzing which (alternative) returns are associated with the reuse of materials
   a. Consider prices relevant to your own area. Prices may differ for an urban area (ex Paris) and for a regional place.
   b. Consider the available time to achieve a good match between supply and demand. The longer the period that information about materials is available before the actual demolition, the better the (alternative) revenues/benefits will be.
3. To analyze which (alternative) benefits are associated with reusing materials from a building.
   a. Estimation of product prices. For reuse of products, search on marketplaces (online and physical), contact experienced parties, and for new products, search in common databases (used for all construction projects)
   b. Contact interested parties to assess whether products can be sold (not just offered), and if so, at what price? And when they need them, or whether they always want to be a buyer (depending on the market, conditions for reintegration, treatment needed, etc.)
   c. Define a price (penalty) in case a buyer has reserved a product but refuses to accept that product after the product has been dismantled.
   d. Analyzing other revenues associated with demolishing a building.
4. To analyze those information aspects that increase the transparency of the quality of materials.

5. Analyzing the combined legal, economic, and technological aspects that ensure that the reuse of materials is guaranteed over time.
   a. Organize liability issues in the supply contracts based on the blockchain registration (tokens), when finalizing the inventory data in the Digital Materials Database (Cirdax)
6. The analysis, maintenance, and improvement of methodologies for making cost-benefit analyses regarding the reuse of materials in a building.
7. Calculating processing or repair costs for a primary quality. In this way, the alternative new price of materials can always be used for the revenue side of secondary materials. The costs of processing and repair are then included on the cost side of the calculations.

2. 8. QUESTIONS AND ANSWERS

The following questions have been addressed in projects on this topic. An answer has been provided for each question.

Question: Is the ownership and use of materials seen as a separate core activity by your organization or your clients, or is this a secondary matter?

Respondent 1: This is a key point as we now consider the importance of material reuse to save CO_2.

Respondent 2: Not part of our activity (engineering firm). Separate core activity for some of our customers who are not interested in reusing materials for their own needs and who are not resellers. Side issue for other customers: want to collect materials for their own needs.

Respondent 3: Since our main activity is the restoration of buildings, there is increasing attention to the reuse of materials that must be removed. This is now a secondary activity.

Respondent 4: This will become a core issue as the municipality moves towards a higher circularity ambition.

Respondent 5: It is not our core business, but reuse is a goal that is set out in the company's strategic plan.

Question: Who owns your materials from a building after demolition? You, your client, or the demolition company that performed their services?

Respondent 1: Depends on contracts.

Respondent 2: In most projects this is the demolition company. Very rarely the building owner (only when a specific material is identified for reuse)

Respondent 3: Usually, the materials become the property of the contractor. Until recently, this was also stated in most tender specifications of the public tender.

Respondent 4: Dependent on contracts

Respondent 5: French law stipulates that a building owner is responsible for his materials until they are removed. In the case of reuse, a contract of assignment must be signed to change the premises if the building owner does not reuse the material.

Question: Concern about the additional program time and resources required due to the extra planning required for things like developing the lease of materials, working with PaaS providers, and spending more time with the tenant to ensure they understand the lease requirements.

Answer: Calculate the cost savings resulting from avoiding replacement purchases under a PaaS model.

2. 9. COMMENTS

The following comments can be added to this chapter.

Comment 1: Interviews with demolition companies show that for them the issue of ownership of materials is subject to change. Where originally there was often an implicit transfer of ownership of materials during the demolition or dismantling of a building, there is a growing awareness that materials primarily belong to the owner. The price of the services of the demolition or dismantling company depends strongly on the value of the materials that are *"harvested"* with the demolition or dismantling, which is why it is also important to know in advance what the exact value of the materials is. For the property owner, the demolition or dismantling company, or the purchaser of the materials. The situation in France, where a legal document is required for the transfer of materials, will be addressed in several places in the future. Especially because materials are becoming increasingly valuable.

Comment 2: Interviews with demolition companies also show that the value of materials is strongly related to the issue of matching these materials with a buyer. In the case of reuse or upcycling of materials, it is not only about preventing the burning or dumping of materials, but also about the quality of the matching process between the supplier and the buyer of materials. Two aspects play a decisive role in this:

1. Insight into the quality of the materials,
2. Sufficient time to complete the matching.

Inventory of materials at the front end of the demolition or dismantling process provides insight into the quality of the materials and ensures that more time can be allocated to matching these materials with the right buyer. Or that all buyers have their containers ready at the building that is to be demolished or dismantled. Both quality and time are examples of information issues that are central to the valuation of materials. Whether these are car parts, as described in The Theory of Lemons by Akerlof (1970), or materials in a building.

Comment 3: Recording property rights strengthens the process of quality and time/matching, because with the help of property rights, term contracts, liability of delivery and combinations with other property rights can also be organised. Materials no longer always must be in the actual possession of the owner of the building but can also remain with the supplier. In this way, the materials become part of a so-called Product-as-a-Service (PaaS). The costs of recording these property rights thus earn themselves back within guaranteed term contracts.

2. 10. REFERENCES

Scientific references

1. The Theory of Lemons, George Akerlof (1970)
2. The Theory of the Firm, R. Coase, (1937)

References within projects

Luxembourg

Construction and demolition waste represents between 25 and 30% of the total waste volume in the European Union, making it the largest waste stream... The same situation can be found in Luxembourg, where efforts are being made to maximise the potential of construction and demolition materials.

Luxembourg law requires that the prevention, reuse and recycling of construction and demolition waste be promoted in accordance with the waste hierarchy. The distinct categories of waste must be sorted and removed as carefully as possible on site to achieve qualitative recovery. If this sorting cannot be done on site, it must be done after the collection of mixed waste.

The legislation also stipulates that when a building is dismantled, an inventory of building materials must be drawn up and submitted to the Environmental Agency (AEV) on simple request. This inventory is a valuable planning tool for resource management, provided that the information is updated during dismantling. The main objective is therefore to promote the separate collection of building materials and their efficient use as resources in Luxembourg.

The Luxembourg Institute of Science and Technology (LIST), in collaboration with AEV, has developed a materials inventory model and an accompanying guide to help those involved in the planning, execution and documentation of decommissioning works to draw up an inventory of the materials and types of waste present, in order to meet their legal obligations as efficiently as possible.

This inventory model is designed to help project owners - who as clients of the decommissioning works - take full responsibility for the planning and preparation of such an inventory. In practice, however, project owners have so far been faced with a certain lack of:

- Information about the materials to be included in the inventory and
- Concrete recommendations for a systematic approach
- Experience in such a process of planning and executing a construction site.

It was decided to develop inventory tools to clarify and facilitate compliance with the applicable regulations. This is in view of the objectives of the revision of the European Waste Directive published in 2018 (Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste).

Shortened programme times for British projects.

Most studies that use reuse of the building and its materials saw or expected a shortened program time. Although safety and deconstruction may require a longer demolition process, a significant portion of the existing building is still on site after this process is completed, and the overall program is therefore shorter.

Although not solely attributed to the use of circular principles, 80 Charlotte Street, and 1 Triton Square both saw significantly faster letting times, with 1. Triton Square seeing the fastest pre-letting in London's West End in over 20 years.

Examples of Products as a Service

Products as a Service (PaaS) has the potential to reduce carbon and material waste through efficient maintenance and refurbishment cycles, as well as take-back programmes that focus on preventing waste and recovering or adapting products for future use. The WLC of PaaS should be considered prior to installation, as there is currently limited evidence that products as a service result in reduced carbon over their entire life cycle and no case studies have been provided that include PaaS. The case studies in this section have been sourced from the websites of various PaaS companies, not all of which operate in the UK.

- **eLight:** Lighting as a Service (LaaS), eLight performs the maintenance of the lighting fixtures and installs an energy metering system to improve the efficiency of energy use. In one school they saved 62 tCO_2 e per year with the predicted annual savings from using eLight. At the end of their life, the original lighting fixtures are taken back by eLight and recycled and reused through Recycling Lives.
- **Signify:** Through Lighting as a service they offer a 50% longer lifespan, indicating a CO_2 saving of the product

The Time Factor in a Circular Economy

In a Circular Economy, time is an important factor. After all, we only speak of circularity if a material or product is also available and usable for new purposes in the future. Circularity concerns a contract with the future about this material. However, we must then ensure that this material can also be supplied in the future, and has not disappeared in the meantime. The dimension of time is therefore also called the fourth component in organizing transactions about materials in a circular economy, in addition to the spatial dimensions. And when displaying diverse types of information in a digital environment, one also speaks of 4D operationality.

Time and the effects of time are represented in the figure in the form of a river. At the source of the river, at the top of the mountain, the water, the materials, are clear and clean. But as the water flows and time progresses, this water is used for all kinds of purposes, such as the provision of drinking water for humans and animals, the generation of energy, the catching of fish, or as drainage for the waste products of a factory. The figure shows that the water at the end of the river has turned black, and is no longer suitable for (re)use.

Circular Building Information Management (C-BIM)

We see the same thing when using information about a building, such as in the case of a Building Information System (BIM) in the figure below. BIM is used in the design and development of a building, but the information in BIM becomes outdated as a building is used and changes over time. The value of the information becomes diluted and disappears, and with it the possibilities to do something with this information for future purposes, as is also intended with circularity. Moreover, there is no digital file or twin available for most buildings, so that we know little to nothing about the materials in the building at the desired time anyway.

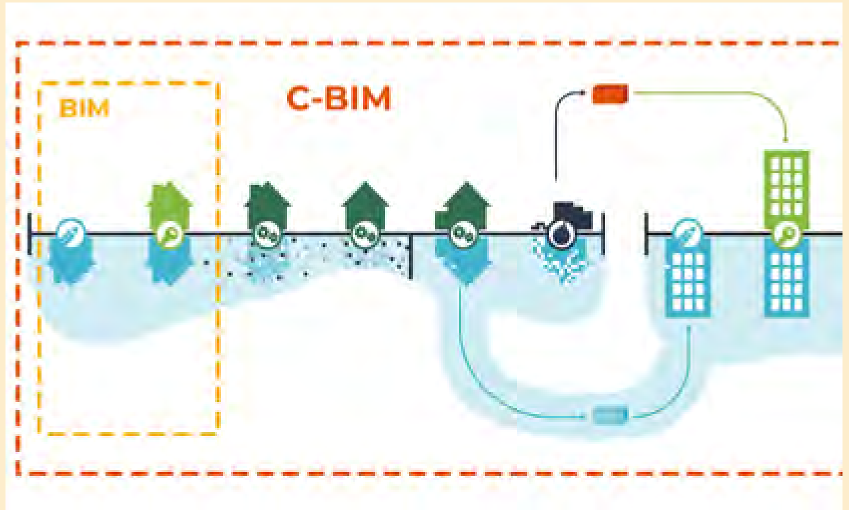
In an ideal situation that is tailored to the future reuse of the materials in a building, the information stored in a digital twin (BIM) is maintained throughout the entire life of a building. The materials present in the building are tracked over time because these materials are identified and have an identification code, which is generated using blockchain technology. With this underlying technology, a material can not only be tracked over time, but can also be combined with various other information needs that have the same technological infrastructure background. Every time something changes in a building and it affects a material, changes can be recorded in a new ledger that is linked to the blockchain registration.

Current situation

- BIM is used for the design and build stage of a new building.
- BIM becomes outdated as a building is being used and transforms over time.
- Most building do not have a BIM.

Ideal situation

- Information in BIM is kept and maintained without a building's life.
- Building without a BIM get a digital twin using scanning tools. This digital twin focuses on reuse of the material.
- AI can be used to extrapolate useful information from these scans
- Before deconstruction takes place, materials can be reserved for a new building



Digital twins of an existing building and thus also the identification of the materials in a building are made by means of an inventory of the materials in the building and the building itself. If drawings of the building exist, this process can be accelerated with, for example, AI technology. Support by other technologies may also be considered, but not every technology has proven itself in this respect. In large-scale inventories, various statistical, econometric and data techniques are used to provide a basis in terms of materials for each building, which can then be verified and supplemented with the help of human effort. The inventories and identifications of materials ensure that it is also known at any time which materials are present in a building, and which will also become available during the dismantling or demolition of a building. These can then also be sold in advance, or be the subject of processing and treatment, so that they can be given a new life.

We call the total of all information for a circular economy C-BIM for *"circular building information management."*

If we look at the river again with this background on the organization of time in a circular economy, we see in the figure above on the ideal situation that we can ensure that the water remains clean in several ways. If that information over time about what flows in the river is not lost. We also call this the institutional design of a circular economy. We will elaborate on this in chapter 12 on marketplaces.

Time also plays a key role in terms of the time available to perform all activities. With the latter we also mean that costs and benefits can only be compared properly if they relate to the same time frame, so that costs in the present do not have to be compared with benefits in the future.

The quality factor time concerns the possibility to inventory suitable materials, as well as to find a buyer for these materials. By inventorying materials early, in accordance with the provisions in chapter 3, the transparency of the quality and availability of materials becomes clear. A demolition or dismantling company then has the preparation time and possibilities ready to remove the materials from a building without much damage to materials. If this time is not available, the quality of the demolition process is much lower and the damage to materials is much higher.

Secondly, the quality factor time relates to finding a buyer. The more time available, the more matching opportunities between the supplier and buyer of secondary materials can be organised. How much time is ideal depends on the buyer network of materials at the property owner or the demolition company, or is related to an improved organisation of buyer and suppliers, for example by means of a digital marketplace (see chapter 12). The less time there is for matching, the lower the returns in a social cost-benefit analysis will be.

The quality of time can be improved by investing in advance in information about the materials in a building. This is done by inventory work, or by means of investments in the environment in which suppliers and demander's meet. In practice, we then speak of a digital marketplace, where trading can already begin, while the materials are still in the building. A trade based on the ownership rights of the materials in a building.

3. INVENTORY AND REGISTRATION OF MATERIALS

3D-scanning: The 3D scanning results in a series of point clouds and panoramic photos, which are stored. In a database or cloud and can be used as input for Reversible BIM.

GPR-ECT (Ground Penetrating Radar): The result of working with GPR-ECT is an im age or map with the location of buried objects.

Reversible BIM (Building Information Management): The Reversible BIM output and sub output can be displayed as follows:

- A colour-coded 3D viewer
- Raw data: Material and reversibility proper ties for each material, e.g. ID, type, material name, function, reuse potential, building level/floor, volume, tonnage, embovdied carbon, waste avoided, carbon avoided, material reused, material group, number of connections, type of connections, number of disassembly steps.
- Summary of reversibility and potential reuse data table
- Overview of raw data of products/materials according to the possibilities for reuse
- Summary tables showing the disassembly effort for each building element
- Score per potential indicator for reuse
- Summary data graph:
- BIM Objects: 3D digital library of reusable elements.
- List of hazardous substances: for example, asbestos, lead, chromium 6
- List of damaged materials

Digital materials databases: The results of inventory processes of the varied materials in a building are registered in the digital materials database. This provides insight into which materials are present in a building.

FOS Meter (fibre optic sensors): The results obtained with FOS provide accurate information about the structural health of the element, related to the material properties that define the structural model.

XRF (X-ray Fluorescence): The XRF identifies the elemental composition of raw materials and helps determine impurity levels to assess the suitability of materials for specific construction processes. It can also identify the alloys, metals, and composites of build ing materials.

MFT (Muon Flux Technology): The output of an MFT is in 3D format and separates steel objects (rebars, strands, pipes, etc.) from concrete or plaster and indicates the locations of defects (corrosion, voids).

AHS (Active Hyperspectral Sensing): The AHS data allows for the classification of material types at any stage of a building's life cycle (raw material collection, demolition).

3. 1. INTRODUCTION

In this chapter we describe the processes involved in the inventory of the various components and materials in a real estate object. We distinguish between different forms of inventory, such as these can be done manually or with the help of various supporting instruments.

When making an inventory of the different materials in a building, the different data about these materials can be recorded in a point cloud, (R)BIM system or a digital materials database. Different forms of metadata are used for this.

Three steps at making an inventory:
1. Make a digital scan of a building
2. Look at the removability of the materials
3. Additional manual inventory for quality control

Inventory has a threefold identity in the **Digital Deconstruction** and **SUM4Re** projects. The first step is to make a digital scan of the building using a scanner. The information collected by the 3D scan can then be imported into BIM software, which is the starting point for an RBIM analysis or Reversible BIM analysis to understand which parts of the building are suitable for deconstruction, i.e. removing the materials from the buildings for reuse in a socially profitable way. The second step looks at the removability of materials in a building. The third step is the additional manual inventory of the materials that have not yet been identified in the previous steps. Information that is stored in a digital materials database.

In this chapter we will distinguish between the three inventory steps just mentioned, where applicable. Otherwise, the techniques and activities will be combined.

This can be further refined by using instruments that map certain materials or parts of a building, or collect certain qualitative data about the materials and the buildings. These instruments are central to the **SUM4Re** project.

This concerns:

1. 3D data acquisition for materials and building products with RGB-iMMS & AR.
   This is aimed at the application of iMMS systems that jointly integrate RGB information by means of pin-hole projection for the subsequent identification of building materials and products. iMMS systems with RGB enable the fast acquisition of 3D information and extrapolation of point measurements, while other technologies used **SUM4Re** have limited spatio-temporal resolution.
2. Data collection for identification of materials and construction products with AHS.
   Hereby an extensive library of hyperspectral data building materials whereby an extensive library is being built. Linear methods such as Partial Least Squares (PLS) for regression or Discriminant Analysis (PLS-DA) for classification will be implemented first, as they are better interpretable and applicable to smaller datasets. The development and optimization of AI models at AHS to quantify specific interesting properties related to the building wood materials, focus on assessing the aging and degradation of wood, the most important properties relevant for reusability.
3. Data collection for identification of materials and construction products using XRF.
   The aim of this tool is to build a comprehensive library of construction materials using XRF [OLAR]. To enable real-time identification of construction materials and products on site, AI algorithms trained on a deep database are required with regard to building materials (concrete and asphalt), ICP in combination with optical emission spectroscopy (ICP-OES) is widely used for comprehensive elemental analysis and can detect major and trace elements (composition information).

1. Data collection for complex or hidden elements with MFT.
   The MFT concept provides a unique data point those competing technologies (such as ultrasound, GPR and X-ray) cannot physically reach, and even provides 3D information for BIM creation. MFT focuses on (1) a generation of model-based simulations using the Geant4 software platform (for GEometry ANd Tracking), including cosmic particle sources such as CRY (Cosmic-ray shower generator) or MPS (Muon Parametrisation Source). The aim is to provide reliable 3D imaging of internal geometries, combined with density and/or atomic composition data of materials.
2. Data collection for complex or hidden elements with GPR-ECT.
   The addition of GPR & ECT in a single device enables material identification (metal vs. non-metal) of rebars/concrete and wood, as well as accurate dimensional information of internal components from 3D AR images acquired with GPR.
3. Structural health monitoring system with FOS. The deployment of the FOS tool provides an integrated structural health monitoring system, the key steps of which are:
   a. Identification of target structures;
   b. Definition of a risk-based assessment framework;
   c. Creation of predicted responses based on a suite of local models;
   d. Selection of appropriate FOS sensors to capture the actual structural response (e.g., accelerations, deformations, etc.) and other variables (e.g., temperature, humidity, etc.);
   e. Installation and inverse modelling for calibration of the system; and (6) Damage identification by applying AI techniques (e.g., neural networks) to the collected structural response data.
4. AI Algorithm Development for C-BIM Automation.
   AI is used in **SUM4Re** to develop solutions to quickly identify materials, construction products and components of existing buildings and infrastructure in urban areas before demolition. Analysis of relevant properties, mechanical behaviour, and structural safety according to potential reuse, repair, or recycling,
5. Automated AI geometric modelling from 3D data.
   The aim of this method is to design and implement point neural networks to identify materials and building products, and to improve the algorithms that use point clouds as input, using both conventional systems (TLS/iMMS) and AR devices (glasses and tablets). Point neural networks are currently the most widely used processing technique due to their high capacity to extract complex features and search for relationships in large 3D data.

All the activities entail work and therefore also costs, which we must be fully aware of. In addition, we look at these activities in the form of services derived from each other. This means that the digital scan of the building provides the boundary conditions for the removability analysis and the material inventory. And the removability analysis defines the possible depth of the material inventory, whereby the instruments from **SUM4Re** increase the quality of the materials involved. We must also investigate how these forms of inventory can be easily organised and multiplied, so that multiple people and organisations can perform these tasks and thve people involved in this process are not hindered by capacity restrictions.

A questionnaire has been drawn up within the **SUM4Re** project on all these angles, which provides more insight into such aspects. We will further clarify and elaborate on these in this chapter, so that insight can be obtained into the effectiveness and efficiency of the various interventions that are possible for making an inventory of the materials.

3. 2. INPUT

For the inventory of materials in a building, one can use a manual inventory by deploying a qualified employee in the field of making a materials inventory or an automated inventory using a 3D scanner or iMMS systems conducted by a qualified employee.

1. A specialized RBIM expert can be deployed to inventory the removability of materials in a building.
2. A digital material database can be used to record the various data resulting from an inventory. The same applies to a BIM system, as well as a server with a database to store the point cloud information and panoramic photos that emerge from 3D scanning.
3. A special form of registration and metadata is the blockchain registration of the properties of materials in a digital materials database. This is aimed at recording the material passport of a material in a building, and thus also records the property rights to the materials. This possibility is the subject of Chapter 4.
4. For specific information about a building or the materials in a building, instruments such as AHS, XRF, MFT, GPR-ECT, FOS and AI can be used, as described in the introduction to this chapter.
5. In addition to the tools that can be used to make an inventory, other activities are needed as input into the inventory. These include site visits, virtual visits, information and data collection about a building, and audits regarding toxicity and hazardous materials.

About a Site Visit the following input is required:

1. Prepare the visit with plans about the building (paper or tablet), maximum information about the building and the existing products, focusing on products to be evaluated.
2. Prepare the logistics of the visit with the building owner to optimize the results of the inventory, to have easy access to the local situation, to have light, to access the elements, etc.
3. Be a team of two people with at least one construction/reuse expert.
4. In some cases, use the visit to scan.
5. Take photos of the products and the location of these materials
6. Try to look behind elements to see connections and hidden products.

The following input is required for a Virtual Visit:

1. Provide access to project stakeholders. Provide simple guidelines for using tools and applications.
2. Organize a short presentation when there is an online meeting, in which the tool or building is presented.
3. Communicate about the possibility of a virtual visit to the building for potential buyers/users of the (reusable) products.
4. Ask for contact details of the people and organisations who want to visit the building. Get feedback on elements they are interested in.

About the collection and consultation of existing building data, the following input is required:

1. For a site visit it is necessary to consider all available information on the construction of a building. This information allows an initial assessment of the construction components and their compatibility with a reuse process.
2. The main sources of information are technical and regulatory audits, plans and drawings, technical documents on products, tenders, information on renovation projects, history of the building.
3. Ask the building owner to gather all available information he has internally and, depending on the typology of the building, to search for historical information in public archives. If necessary, contact can also be made with the architectural firm that supervised the construction.
4. Use existing tools to search for information in many documents (ex MASSDOC).
5. Create a repository (cloud) and a glossary for all collected documents.
6. For an RBIM assessment the following additional information is required: construction date, specification of renovated parts and individual data of each renovation.

Regarding mandatory audits (hazardous material, waste, etc.) the following input is required:

1. Conduct mandatory audits for the project (lead, asbestos, hazardous waste, C&D waste, etc.).
2. Ideally, do this before the on-site inventory to avoid contact with hazardous materials, to locate recoverable products, and to integrate all data into supporting tools of the approach.
3. Contract specialized/authorized auditors.
4. Ask for details about the specific presence of hazardous products, contact with other elements, photos, if possible
5. Create a repository (cloud) and a glossary for all reports.

3. 3. PRODUCTS AND SERVICES

3D scanning

The 3D Scan is the first step in creating the digital twin of the building to be deconstructed. Laser scanning has been around since the 1960s. But the first 3D scanner used by surveyors and engineers appeared in the late 1990s.

One of the main advantages of using 3D scanning is that it is fast and accurate enough to give the best realistic image of an entire building. For the **Digital Deconstruction** project, the mobile scanner VLX (manufactured by NavVis) was used, which scans (or maps) approximately 10,000 m² per day. And at the same time, many panoramic photos of the building are taken.

After processing the raw data, the building can be visited via a web browser. The end users can virtually visit the building and manually add information to a part of a building and share this information with the other stakeholders. They can take measurements of the point cloud or update and download a part of it.

During the 3D scanning, a lot of geometric data is collected (point clouds and panoramic images) that can be used to automate the inventory of a building. Computer animation is used to automatically identify the assets (doors, windows, lights, sensors, ...) and to **geolocate** them with the Indoor Viewer. The point cloud is used to create the Reversible BIM model and the list of assets to provide accurate information to the material database.

Reversible BIM (RBIM)

The Reversible BIM module is a BIM application based on the Durmisevic model. The RBIM is based on a captured point cloud (from 3D scanning). Using the **Revit plug**-in for digital reversibility assessment, RBIM enables the reconstruction of the digital model of the existing building. An analysis that includes the spatial dimensions, material relations, quantities and reversibility and reuse properties of a building and its components.

A Reversible BIM has two integral features:

1. Digital parametric representation of buildings with information about geometry, position, function, relationships, and connections between building elements.
2. The Digital Reversibility Assessment (DRA) provides an assessment of reversibility/removability/reuse potential. This is designed to assess how easily building products and materials can be recovered without damaging surrounding components.

The Reversible BIM module is therefore a digital application for the assessment of reversibility and disassembly of buildings and construction products. This results in the calculation of the reuse potential of construction products and materials. At the same time, RBIM stores and manages data on building materials, life cycle, functions, dimensions, volume, *"embodied CO_2"* and reuse potential in a BIM environment. An environment that enables micro and macro analyses of the circular capacity of the building and its material during the life cycle of the building.

As such, the model generates information about:

- Several deconstruction/restoration steps for building materials,

- The degree of damage to material after repair,
- The potential score for reuse
- The effort required to recover,
- The reapplication of materials that indicate the ecological and economic value of recovered materials.

The removability and reversibility assessment are performed at three levels of the building's technical composition (i.e., building, system, and component level) (Durmisevic 2019, 2020).

The score for reuse potential (RP), based on a digital reversibility calculation, varies between 0.1 (worst) and 0.9 (best). It sorts all building elements into three categories:

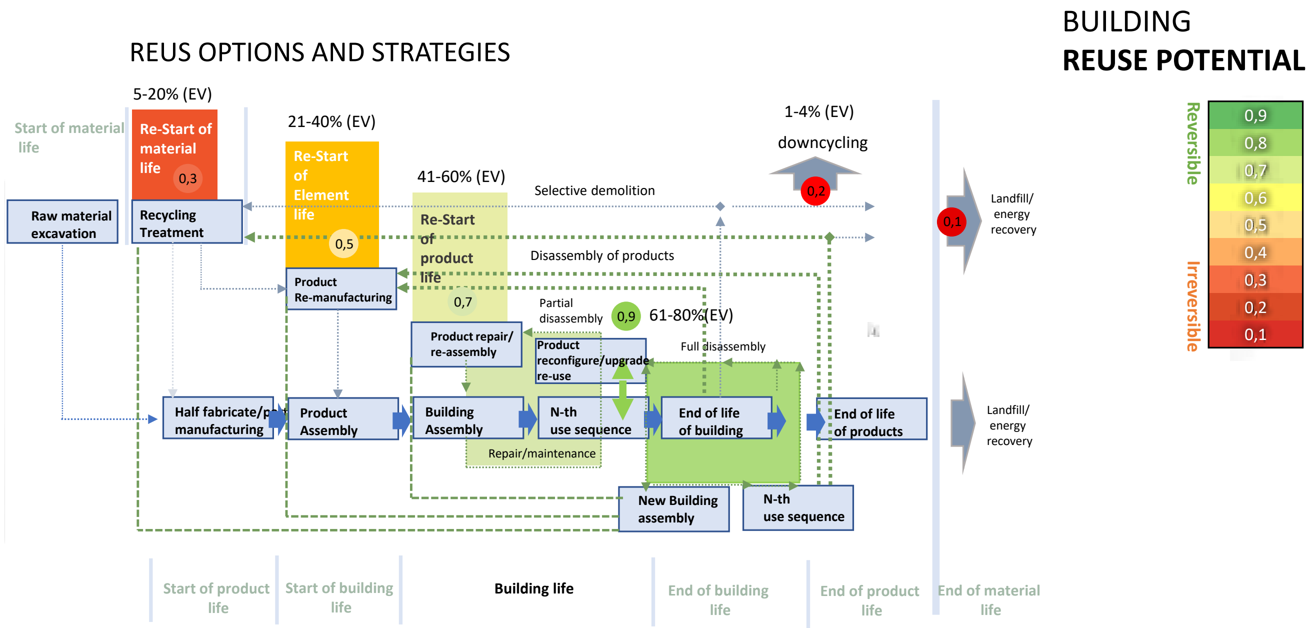
- Irreversible buildings (building elements/ materials with low potential for reuse, materials are in a deteriorating cycle towards recycling and downcycling),
- Partially reversible buildings (partial reuse potential, materials can be remanufactured or reused after major repair and
- Reversible buildings (whose materials can be reused directly or after minor repair or reconfiguration).

The reversibility of buildings indicates the possibility for reuse of products and materials after they have been recovered. As it measures effort and time, the model also considers the number of dismantling steps and operations required to restore an element. The models are the result of a solid basis for ecological and economic assessment of dismantling and recovery activities.

The shorter the feedback loop of the life cycle of a construction product, the lower the environmental and economic impact and therefore the higher the score for the potential for reuse (see figure below). This calculation system is based on Model Durmisevic published in 2006, updated in 2009, and evaluated and verified during EU H2020 BAMB-Buildings as Material Banks Project (Durmisevic, 2006), (Durmisevic, 2019).

The digital materials database

The Digital Materials Database is an IT application that stores information about materials in a building in material passports. In the **SUM-4Re** project, two Digital Materials Databases are used for this purpose, namely Cirdax and Concular. It makes information about all materials transparent, so that every owner knows what he owns in terms of materials. The Digital



Materials Database can be seen as a supporting system to make a cost-benefit analysis for reuse of materials, because it can store all information about this analysis, or by providing statistical data resulting from previous inventories and analyses.

How to use and enter information in the materials database?

A Materials Database can give materials an identity. For this, each material needs to have its own passport. This passport stores information about the materials in a building, which is obtained by making an inventory of each material using 3D scans and manual activities. Normally, inventory activities are performed by people with knowledge about buildings and materials who walk through the building and *"write down"* the materials they see on each floor and in each room. Activities that can be supported by 3D scanners, RBIM models, drawings of a building or additional tools such as AHS, XRF, MFT, GPR-ECT, FOS and AI.

The Cirdax Digital Materials Database has an inventory support application that makes it easier to enter information about the materials. Property owners, their staff or a specialized consultant can learn about this inventory process with about two days of training. Normally, training to learn how to use Cirdax starts with only one room and only a few materials that need to be registered. An example that can also be prepared in Excel.

In addition, material properties in terms of size, weight, colour, location in the building etc. are included in the passport, as is the notification about the removability of the material from a building. Information that is collected from Reversible BIM processes. The Reuse score of a material is an integral part of the passport and tells us whether a material can be used alternatively, including a correction for the costs of removal and processing for alternative use. The scores can also include data from the instruments from **SUM4Re**.

How to use and exploit the output?

A Materials Database provides the owner of a building and the materials in that building with information about the materials in terms of quantity and quality, which can be combined economically and financially. It provides information about the economic, social, and financial value of the materials, which is used on the benefit side of a cost-benefit analysis. By economic value we mean the sum of both the financial and the social/environmental value of the materials.

Registering every material in a materials database is economically feasible for all materials that can be disposed of easily or with average effort according to the reuse score from the RBIM. For those materials that require a lot of effort to inventory, register, store and sell, it is necessary to perform a cost-benefit analysis. For such an analysis, it is important to also include a lot of qualitative information, such as that obtained from the additional instruments of **SUM4Re**, because qualitative information is especially value-enhancing for materials.

In addition, it also provides a transparent picture of the quality of the materials and the costs involved in inventions the materials and processing them in such a way that the materials can be used alternatively. Performing a manual inventory is described in Manuals. This inventory is a professional process performed by an expert.

The inventoried data from a manual or automated inventory can be included in a digital materials database, such as Cirdax or Concular. This data can then be used again by applying APIs regarding data exchange. The registration of a material passport in the Euthereum blockchain is used to register property rights. That is, a digital link has been created between the Digital Materials Database (in the **DDC** project this is Cirdax) and the Euthereum blockchain using APIs on several servers. For each material stored in the digital materials database, a material passport has been generated with a blockchain attribute (hash). This #hash can also be found on the Euthereum blockchain.

Through a verification process using the blockchain, the underlying characteristics of the material in the material passport can be continuously verified. Changes to the material passport can only be legally valid if the characteristics of this updated material passport are added again as a ledger line in the Blockchain. In this way, each material gets its own demonstrable identity, which can serve as a product for further implementation of costs and benefits, because other rights can now also be linked to these rights. See chapter 4 in this manual for more explanation.

3. 4. METHODS, TECHNIQUES, TEMPLATES AND INSTRUMENTS

The following Methods, techniques, templates and instruments can be used in an inventory proces.

1. A description/guide of the point cloud scanning process with NavVis.
2. A description of the scanning process with iMMS
3. A description of the scanning process with **Hololens** AR
4. A description/manual of the RBIM process with the Revitt plugin.
5. A description/guide of the manual inventory process
6. A manual for using the Digital Materials Database
7. A Guide to Using Blockchain Integration with a Digital Materials Database
8. A guide to using a FOS meter.
9. A guide to using an XRF instrument.
10. A guide to using an MFT instrument.
11. A guide to using an AHS instrument.

3. 5. RESULTS

3D scanning

The 3D scanning results in a series of point clouds and panoramic photos, which are stored in a database or cloud and can be used as input for Reversible BIM. The different data can be studied using a web browser or 3D viewer. LiDAR technology uses 3D data, so we can identify any element with a characteristic geometry, including materials with a characteristic surface. AR technology, on the other hand, allows us to manually annotate other interesting information that the operator knows. There is a difference between raw materials and materials because raw materials imply the composition of the materials.

Reversible BIM

The Reversible BIM output and sub output can be displayed as follows:

1. A colour-coded 3D viewer, which shows the degree of reversibility and reuse of building products/materials by colour.
2. **Raw data:** Material and reversibility properties for each material, e.g. ID, type, material name, function, reuse potential, building level/floor, volume, tonnage, embodied carbon, waste avoided, carbon avoided, material reused, material group, number of connections, type of connections, number of disassembly steps.
3. Summary of reversibility and potential reuse data table:
   a. **At building level:** global total (average reversibility and reuse potential score of all materials in the buildings), total volume, tonnage, CO_2 embedded in the buildings, average waste avoided,
   b. **At system level/building function level:** reuse potential, avoided waste, CO_2 per function such as: Load-bearing capacity/base, Housing, Separation, Finishing, Equipment, Intermediary, Vertical communication.
   c. **At product/element level:** reuse potential, avoided waste, CO_2 per product type and number of products, e.g., facade column x, doors y, doors z, steel profiles x, etc.
   d. **At material level:** reuse potential, avoided waste/reusable tonnages, CO_2 per material type, e.g., aluminium, steel x, wood MDF y, concrete z, bitumen etc.
4. Overview of raw data of products/materials according to the possibilities for reuse, for example:
   a. Products and materials that can be directly reused or minor repairs,
   b. Materials that can be reused through major repair or remanufacturing,
   c. Materials that can be reused through recycling,
   d. Materials that have no reuse option
5. Summary tables showing the disassembly effort for each building element, including:
   a. Number of connections,
   b. Type of connections,
   c. Number of disassembly steps per building element
6. Score per potential indicator for reuse such as:
   a. Reversibility of connections,
   b. Number of relationships,
   c. Hierarchical dependencies,
   d. Disassembly sequence
   e. Remaining life cycle/life cycle coordination
7. Summary data graph:
   a. Distribution of embodied tonnages of material and carbon by material and building system/product and by category of reuse option Embedded tonnages vs. reuse of material/waste avoided by category of reuse option
   b. Embodied carbon vs. avoided carbon by reuse option category
8. **BIM Objects:** 3D digital library of reusable elements.
9. **List of hazardous substances:** for example, asbestos, lead, chromium 6, etc.
10. List of damaged materials

How to use and exploit the RBIM outputs?

1. RBIM outputs are multi-layered and can be used as decision support by different stakeholder groups.
2. RBIM output provides information on the quantities, volume, weight, per material and product type, including their *"embodied CO_2"*. As well as the Reuse Potential Score which is reflected in the indication of avoided tonnages of CO_2, waste and raw material, as well as the reuse options of materials.
3. As such, RBIM output is used to develop reuse strategies and define a more detailed circular ambition, which is then integrated into tender documentation and requirements for the constructor.
4. The calculations reflect the effort required to recover material as well as the effort required to reapply material.
5. The calculated values reflect potential labor, equipment, and virgin material required for the recovery and reapplication of harvested material. Therefore, RBIM results are also used for preliminary elaboration of the most desirable reuse options for a given economic objective of the project.
6. Based on a library of reusable materials, the building owner can purchase materials before demolition begins.
7. RBIM results provide information on the position of elements that need to be repaired, as well as disassembly steps and operations that indicate an element can be easily repaired. This is used to develop deconstruction and sorting strategies.
8. Reversible BIM creates a digital library of BIM objects of reusable elements, allowing architects to start using reusable elements in their modern designs before the building is deconstructed.
9. The digital library of BIM objects of reusable elements is used by manufacturers who remanufacture and refurbish reusable elements. BIM objects are then used by manufacturers as part of their sales catalogues.

Government agencies

The digital reversibility assessment score reflects through its score the building's ability to enable a circular material feedback loop. As such, RBIM defines a building's circularity profile and classifies all buildings into 5 circularity profiles from irreversible to fully reversible building products and materials. This is used by governments to standardize the performance of circular buildings, define circular ambitions through a building code and smooth the transition from linear to circular economy in construction.

The digital materials database

The results of the various inventory processes of the varied materials in a building are registered in the digital materials database. This provides insight into which materials are present in a building.

Using the various metadata that can be linked to a material registration, each material is given an identity. For example, characteristics can be added to this identity that relate to size, quality, removability, etc.

By linking the registration of the materials to the blockchain, the materials also get a strongly defined and fixed ownership right. This in turn can be used to link the rights to these materials to the possibility of selling the materials in a marketplace. Or to arrive at a material balance of a building based on the sum of the rights of these materials. Or to link these rights to other rights, such as CO_2 emission rights.

GPR-ECT

The result of working with GPR-ECT is an image or map with the location of buried objects. Non-destructive detection and identification of embedded materials offers a clear advantage for the circular construction economy. The presence or absence of certain materials (e.g., reinforcement) and their condition certainly contribute to the best practices for preventive maintenance.

FOS Meter

The results obtained with fibre optic sensors (FOS) provide accurate information about the structural health of the element, related to the material properties that define the structural model in the finite element software. Some of these properties are the modulus of elasticity, shear modulus, yield strength, etc.

XRF

The XRF identifies the elemental composition of raw materials and helps determine impurity levels to assess the suitability of materials for specific construction processes. It can also identify the alloys, metals, and composites of building materials. It then verifies the composition of final products (e.g., bricks, concrete blocks). In terms of building elements, it is a non-destructive test that identifies the elemental composition of building components such as beams and columns. It can also be used to identify hazardous materials (e.g., asbestos or lead) in older buildings. The ICP-OES provides accurate concentrations of trace elements and contaminants in raw materials. It can be used to certify raw materials to quality and safety standards, such as heavy metal limits. The ICP-OES can be used to analyze coatings, adhesives, and protective layers for chemical stability. In terms of use in circular construction, it ensures high-quality and safe input for construction and reduces waste.

The final output of the XRF shows the concentration of specific elements (e.g., Fe, Cu, Pb, Zn) in the sample, usually expressed as parts per million (ppm) or percentage (%). The final output of an ICP-OES shows the concentrations of elements in the samples, usually expressed as parts per mg/g. These outputs can be used as an initial screen to qualify and quantify heavy metals. If the concentration is lower than allowed, they can be reused, thus supporting the circular construction economy.

MFT

The output of an MFT is in 3D format and the ML algorithm separates steel objects (rebars, strands, pipes, etc.) from concrete or plaster and indicates the locations of defects (corrosion, voids). The classification is based on products and defects according to the C-BIM framework.

AHS

The AHS data allows for the classification of material types at any stage of a building's life cycle (raw material collection, demolition). This can be particularly useful for screening materials before/after demolition for re-use feasibility. The raw data consists of hyperspectral images, i.e., images with ~100 *"colours"* instead of the usual red-green-blue (RGB) colours of typical digital cameras. This data can be interpreted by other machine vision instruments for the detection of surface damage, cracks, and specific materials that are not visible with normal cameras (the AHS works with infrared light).

The processed hyperspectral images allow to classify materials (e.g., wood types, concrete, etc.) and to assess the quality of the material (e.g., if there is too much moisture, mould, rot, etc.). The results only concern the surface of the scanned elements since the infrared light does not penetrate deeper than a few millimetres. The results allow us to screen the materials for reusability faster than with single-point scanners.

3. 6. QUALITY FACTORS

One of the most well-known problems with the reuse of materials is that a new user is often unaware of the quality standards that used material still meets. By inventorying the characteristics of a material and recording them in a digital materials database, this form of asymmetric information is eliminated. As a result, material is given a quality basis again, which can be addressed for further reuse. This issue was originally described in: George Akerlof, The Market for Lemons, 1970. Better quality increases the value of the materials, which also contributes significantly to higher labour productivity in the reuse of materials.

SUM4Re is aimed at improving the qualitative information about materials. The instruments used for this contribute to this quality improvement as follows.

iMMS Lidar

Qualitative information: LiDAR makes it possible to identify visible surface damage. However, depending on the size of the damage (e.g., small cracks), it can be overlooked unless specific scans are made to look for it. This takes much more time than a scan to generate a 3D model. With AR, visible damage can be manually labeled.

Reducing information asymmetry: Good.

Once the elements are digitized and labeled in 3D, it is easier to know the exact dimensions and location of the damage.

GPR-ECT

Qualitative information: PR-ECT can provide qualitative information on the deterioration (related to corrosion processes) of the first reinforcement layer on concrete. It can also provide qualitative information on the moisture content and concrete cover of the same material described. It can also provide information on the density of asphalt, the interface structure between asphalt and concrete (debonding) and the presence of defects (such as cracks and voids).

Reducing information asymmetry: Reasonable.

FOS

Qualitative information: The fiber optic monitoring system provides an accurate picture of the current quality/health of the material, also about removability. The result is that the structural element is approved for use at another location/in another building.

Reducing information asymmetry: Reasonable.

The result is an accurate picture of the health status of the structural element, which is created objectively and reduces the asymmetry between buyer and seller.

XRF

Qualitative information: Both the portable XRF and the ICP-OES provide qualitative information that is essential for understanding materials, products, and their properties. The XRF identifies the presence of elements in a sample. It can be used to determine whether a material meets overall quality requirements by identifying impurities (e.g., arsenic or lead in metals or soil). The XRF can be used to detect surface treatments or coatings and provide insight into whether a material has been treated for durability (e.g., galvanized steel). The XRF can be used to detect corrosion products on structural components, such as rust (iron oxides) or sulfates. In terms of environmental safety, the XRF can be used for hazardous substances in building materials (e.g., lead in paint, arsenic in treated wood or cadmium in roofing materials). The ICP-OES provides insight into the amount of trace elements in raw materials or products and indicates the presence of contaminants. In addition, the XRF can be used to assess chemical homogeneity and thus ensure consistent quality of materials. It also analyses degradation by products, such as leached metals, to assess the long-term stability of the material. In the case of ICP-OES, it can be used to measure traces of contaminants in materials or their environment..

Reducing information asymmetry: Excellent.

Tools such as portable XRF and ICP-OES are essential for reducing information asymmetry between buyers and sellers of specific materials. They ensure that both parties have accurate, dependable, and objective data on the materials exchanged, promoting transparency, trust, and fairness in transactions.

MFT

Qualitative information: Current capabilities are focused on assessing integrity based on location and geometry, and work continues to provide quantitative information on materials and defects.

Reducing information asymmetry: Good.

We can guarantee that there is x number of materials if the input is known. This means that the seller must know what he is selling (the original design or the number of materials).

AHS

Qualitative information: The AHS provides information about the condition of the material (for example, whether the wood is moldy or rotten) and about the specific material type (pine, etc.). The information only relates to the surface of the material but can be combined with other sensors to get a broader picture.

Reducing information asymmetry: Reasonable.

I cannot assess the extent of this contribution, as I am not aware of the current situation regarding the information asymmetry between buyers and sellers of building materials.

3. 7. PROCESS ACTIVITIES

3D scan with Navvis, iMMS or AR

1. 3D scan on location

1. Evaluate whether a 3D scan is relevant for the project. It may depend on the typology and size of the building, budgets, distance of the building to the stakeholders, support, and management teams. Discuss the issue with support and project management teams.
2. **Set the expectation for the 3D model:** integrate the 3D model into a BIM program, allow a virtual visit, allow adding POI, communicate, provide a technical tool for the project management team
3. A dedicated service provider experienced in reuse approaches can provide point clouds and segmented 3D models. And ideally a 3D viewer that is easy to access/use.
4. Determine the time at which the 3D scan can be made ideally, it should be made when the building is empty, so that the building appears on the 3D scan as it will be when the demolition starts. Also, pay attention to the natural light conditions. Good natural light helps with the scanning.

2. 3D model viewer, add info and POI.

1. Choose a relevant tool that has been tested before, or that has already been used. A tool that has experience with reuse approaches. Preferably ask the opinion of previous users.
2. Preferably choose a tool for which you can give stakeholders free access to your project.

RBIM

1. 3D model segmentation – BIM

1. To be conducted by the service provider unless the expertise is available internally.
2. Define with the service provider the required level of detail, the use of the 3D model and other tools used.
3. Define intermediate stages in the process where the consulting firms (architects; engineers) can gain insight into the ongoing segmentation of the building to see whether the defined goals are still realistic or need to be revised.

2. Stock. First level of information

1. The level of information should be assessed depending on the importance of the products for reuse. Do not waste time detailing products that cannot be properly deconstructed or reused and concentrate on all products with potential.
2. The information required depends on the assorted products and materials in a building. General: product, material(s), condition, dimensions, brand and reference of the product, location in the building, photo, quantity, + if possible and useful: information about disassembly, reuse.
3. If digital tools are used for the rest of the process, use the digital materials database to record the various data resulting from an inventory.
4. In case RBIM is applied for the inventory of reversibility/disassembly and reuse potential, the above-mentioned information about the number of products, their dimensions, disassembly potential is automatically generated from RBIM.

3. Disassembly tests

1. Not mandatory, but ideal in some cases.
2. Disassembly tests allow us to identify the best method of disassembly to maintain the integrity of the product. If possible, try to observe the potential of physical disassembly during the visit, or the later visit organized after identifying products.
3. Arrange a specific visit with the dismantling company. They can provide an expert view and advice.
4. Drawing up a contract for the disassembly tests
5. The time for disassembly testing must be provided in the project planning (see *"project schedule."*

4. Detailed inventory

1. Complete the inventory with all the information found, including the tests.
2. If the process involves the use of digital tools, use the digital materials database to record the various data resulting from an inventory.
3. The level of detail may vary depending on the function of the desired products and their reuse potential.
4. The detailed inventory supports information that many actors need throughout the process. It must be accessible and up to date.
5. Provide access to the inventory to all project actors. Provide a usable and understandable database and/or tool. Provide guidelines for the use of the database and tools if necessary. If a commercial tool is used, provide free access to stakeholders.
6. Provide a synthesis of product quantities/typologies, etc. to collaborate with actors using common and understandable data.
7. Communicate the inventory to the target network to find potential buyers and users. For example, using a digital marketplace.
8. Update the information with products and stakeholder interests, products sold, deconstructed, and attached documents.

5. Evaluation of reuse potential (RBIM)

1. Contact experts to know the conditions of an RBIM assessment and access to an RBD (Reversible Building Design) platform with guidelines and protocol.
2. Collect all necessary information. See section 4, previous results on the **DDC** project.
3. Preferably provide a segmented 3D model that can be used by experts.
4. Discuss the objectives of the assessment, define the intended products/parts of the building/desired ambition regarding CO_2 reduction, avoidance of raw material use/desired ambition regarding material reuse and waste disposal
5. Use the colour-coded 3D reversible model viewer within NaVvis to visualize reuse options of building products that match the colour code and their distribution throughout the building.
6. Use the overview of materials with high reversibility/disassembly and reuse potential and information on dimensions, quantity, embodied CO_2, product positions to investigate the market and industry conditions for their recovery or processing.

6. How do you create an RBIM of a building?

Creating an RBIM for deconstruction projects begins with the collection of point cloud files from 3D scanning, technical drawings, and bill of materials, if available. Based on this data, a basic Reversible BIM representation of a building is created following the RBIM modelling protocol. Once a basic model is created, the reversibility and disassembly of the components is analyzed using the RBIM plug-in. This plug-in creates an automated overview of the number and type of relationships that elements have between each other and hierarchical dependencies that pose obstacles to a smooth recovery.

RBIM Plug-ins assess indicators that reflect the reuse potential of individual elements, such as:

- Number of relationships
- Hierarchical dependency of individual element
- Type of connections and degree of damage
- Assembly/disassembly sequences
- Life cycle coordination

The final reuse potential is calculated considering different weighting factors of the above-mentioned individual indicators relating to the reuse potential.

Digital materials database

When making an inventory of materials in a real estate object and registering the characteristics of these materials in a digital materials database, the following process activities are involved:

1. Collecting drawings and other documents relating to a building
2. Capturing those elements of a building that are already known or not yet known.
3. The physical or digital inventory of the materials in a building as a supplement to the preliminary analysis.
4. Recording all data in a digital materials database.
5. Creating a material passport of a material. Providing an identity to a material in a building.
6. Recording the material passport in the blockchain. Providing a verifiable identity to a material in a building.

GPR-ECT

An operator must manually scan using the *"GPR instrument"* by pushing the machine over the scanning surface. This type of instrument is usually a lightweight, portable device.

FOS

This sensor system provides accurate measurement of the stress exerted on structural elements under various loading conditions. It requires a continuous electrical current (220 V) to continuously monitor the stress and can be remotely controlled.

XRF

XRF and ICP-OES require a trained operator to operate the instrument, prepare the sample for measurement, and interpret the results. Calibration techniques and a safety protocol are also required. Time is required for sample preparation, measurements, and data processing. Sample analysis requires the use of vials, sample containers or sample bags, and desiccants to reduce the moisture content of the samples.

MFT

The scanners operate passively, and no personnel are required on site for data collection. Preparation for measurements includes a site visit and document study to determine the most relevant measurement locations. Site preparation may require scaffolding, a crane or other additional equipment to position the scanners. The time to set up the scanners typically ranges from 1 hour for simple cases such as placing them in the designated location to 8 hours for extensive scaffolding or hoisting. The average time is 4 hours. One scanner requires a minimum of three people for manual lifting or two people for lifting equipment. One scanner (including PC) requires approximately 500 W of power; typically, there are two scanners on site, so 1 kW of continuous power is required. A 220 V power outlet is sufficient, and batteries can be used for shorter measurements. Scanning can take up to a week and requires no intervention. For larger areas, moving from location to location varies from 30 minutes to 8 hours, depending on accessibility and the need for scaffolding or hoisting equipment. Typically, moving the location takes 1.5 hours. Completing the measurements takes 30 minutes to 6 hours. Typically, 1 hour. Additionally, it may be necessary to measure the exact positions of the scanners if a global or system-level coordinate system is used. This allows for the correct positioning of internal elements. The current dimensions of a scanner are 1750 mm x 1000 mm x 400 mm, and the weight is 80 kg.

AHS

Since it is currently a prototype, it requires skilled personnel to operate it and analyze the data. In the future, a user-friendly product could be operated by non-skilled personnel on site and perform data analysis using built-in software.

3. 8. QUESTIONS AND ANSWERS

In projects on this topic the following questions have been asked. Every question has an answer.

Question: Have you used the Indoor Viewer?

Respondent 1: Yes, we used the Indoor Viewer to check some objects after receiving the review from our design team.

Respondent 2: Our architects received all the data by email and used their own drawing program to load the data and extract vector plans (floor plans, measurement plans, etc.) to provide clear plans within the public tender. The building owner checked the data once in the Indoor Viewer.

Respondent 3: Yes, we used the Indoor Viewer to check some objects after receiving the review from our design team.

Respondent 4: Yes, we used the Indoor Viewer to present the station. It is an easy way to discover the building without moving. The scan was made late, otherwise it would have been especially useful for the reuse diagnosis.

Question: Have you used the measurement tool? If so, what is your feedback?

Respondent 1: Yes. Very easy to use and convenient.

Question: Have you shared the Indoor Viewer with other stakeholders?

Respondent 1: Yes, with our design team (responsible for resource assessment and reuse/recycling strategy)

Respondent 2: Yes, with the owner of the building

Respondent 3: Not yet, but we will include this link in the public tender documents so that contractors can virtually walk through the buildings.

Respondent 4: Yes, with our design team responsible for resource assessment and reuse/recycling strategy.

Question: What functionalities would you like to add to the Indoor Viewer?

Respondent 1: The ability to link a Point of Interest to a file.

Respondent 2: It would be interesting to link a Point of Interest to a description in the material database.

Respondent 3: Item recognition would be especially useful.

Question: What are your preferences?

A. Create RBIM yourself or have external experts create it and use Revitt for the digital reversibility assessment?

B. Only interested in output presented in tables and exported as Excel files for further own data analysis?

C. Only interested in data as mentioned in question 1 in PDF format and graphs?

D. Interested in all forms of output and RBIM usage?

E. Are there one or more Reversible BIM outputs that you can think of that should be added to the list of outputs?

Respondent 1: For old buildings it can be interesting to indicate the heritage value and to see which materials - in whatever condition - must absolutely be preserved (for example for subsequent restoration)

Respondent 2: We would like a written explanation of all the graphs and advice to develop a strategy, because now we do not know how to use that data. The output of RBIM needs to be analyzed to produce a reuse strategy that is customized to the project. How do you do this?

Question: Are there any material properties you can think of that should be included?

Respondent 1: Heritage value, age of the materials, need for conservation (for example due to the unique character of an old valuable material)

Respondent 2: In a manual reuse diagnosis, we look at the disassembly potential but also at:

- The quality of the material: is it old? Has it been damaged by time? Is it healthy?
- Is the material easy to transport and store without damage?
- Is it an element that can be easily reused (wanted element, minor repair needed...)?

Question: Which properties of materials in a building are important to you, so that they can be included in a materials passport?

Respodent 1: Geometric dimensions, Material, Weight, Technical specifications

Respodent 2: Heritage value, age of the materials, conservation needs, number, dimensions, condition, certificates, loose parts (in case), weight, location, how the material is connected to others, special points of attention when removing the material, route to storage.

Respodent 3: For one building (for example 100 windows) how many are reusable (for example: 600 windows can be reused and 400 won't because there is damage)? How to deliver the material without damage? How to store the material without damage? What are the material dimensions? What is the material weight? What is the main component?

Question: How is the quality of reusable materials determined or recorded in your company? Is there a distinction made between reusable own materials or reusable materials from third parties?

Respodent 1: Based on the question that arises (no determination of technical quality such as performance testing). No reuse for our own needs

Respodent 2: Not yet included, but I think our architectural team will check the quality on site. If necessary, specialized companies can perform tests.

Respodent 3: The quality is determined during the reuse diagnosis. There is no difference between reuse for us or for third parties.

Question: Is quality not part of your way of working and are materials only recycled in low quality?

Respodent 1: Currently, recycling is mainly *"downcycling"*, not real reuse.

Respodent 2: Until now, materials have only been reused for downcycling, but we want to change that.

Respodent 3: No, we want to reuse our materials!

3. 9. COMMENTS

The following comments can be added to this chapter.

From the various questions to Project Owners within the Digital Deconstruction project:

1. The **Digital Deconstruction** project and its platform should set 'a standard' for material stocks in buildings.
2. **Inventory:** that material properties, the method of dismantling and advice on where it should go can be added to the *"basic data"* (dimensions, location, description, etc.) in a digital materials database.
3. The Digital Materials Database must be able to search for quantities of materials.
4. For an RBIM analysis you need to know much more (and look behind the curtain): connections, material knowledge.
5. One should have the possibility to use the **DDC** modules independently and not be obliged to use the BIM-Y 3D model and/or RBIM.
6. There should be the ability to integrate small pieces of information into inventories and studies (some of which have value).
7. **CSTB:** in connection with waste audits (new PEMD in France), a clear distinction is made for the time being between the 'waste audit' which includes all materials and the 'reuse inventory' which only includes reusable elements.
8. **Creation of new project:** possibility to integrate parts of buildings and POI from the 3D scan model directly into the structure of the project to be created. Or create in the platform and link with the POI.
9. It would be interesting if the Digital Materials Database and the RBIM could be connected to each other.
10. Genuine interest in adding documentation (documents, links) to the *"Material Information"* windows.
11. **Order of deconstruction:** it should be good to be able to select/propose different types of valorisation value chains
12. It should be interesting to list detailed reuse and recycling of elements.
13. Use Cirdax as a detailed material database to provide an overview of all instrument results.
14. Use RBIM output tables with an overview of products and materials per building function, product type/material with information on usage potential of individual products and material quantities, dimensions and associated avoided CO_2, waste, and raw material
15. Communicate and share the RBIM digital library of reusable elements and their BIM objects with architects, industries, and sales platforms to boost their reuse potential.
16. Use RBIM outputs with overviews of quantities of materials without potential for reuse and requiring special treatments

From the project CB23 (Netherlands)

A construction passport (or 'passport' for short) ensures that the correct information is available in the correct way when the need for that information arises. The need can be a current need, but the availability can also anticipate future needs. By registering information about the objects, passports support the three pillars of circular construction:

1. Protecting material supplies,
2. Protecting the environment and
3. Protecting value.

In this, high-quality reuse of materials on the one hand and reducing the use of primary raw materials and the production of waste on the other hand are the primary goals of using a passport. A passport provides insight into which materials were used in the construction and how they were processed. The form of a passport must be clearly defined, but the content may vary.

The information requirement, based on the available data, is the core of the use of a passport for construction. For the passport, it is important to guarantee completeness, reliability, and accessibility, and thus the practical usability, of data as well as possible. The data that is discussed in a material passport concerns the local context (area, complex) and the nature and composition of the building itself (element/building part/component, building product, material, or raw material). The passport shows the product characteristics and thus the reusability potential during the usage phase through use, wear, maintenance, and replacement. Upon delivery, the data must therefore form a representation of the building as built and during the usage phase as is. It is crucial that passport data regarding future availability of building components are reliably communicated to the data portals for the purpose of reuse. After all, these portals draw their information from this on identity, quality, quantity, and the moment of availability of secondary (building) materials.

Improving data quality

By requiring a material passport in new and existing real estate and accurately inventorying and registering buildings on materials, the sector can increase the quality and completeness of data. In the civil engineering sector, the information delivery specifications (ILS) are the right method to register used materials, by including the material passport in this.

To guarantee the highest data quality, it is important that attributes of buildings are recorded in a passport by experts in that field immediately after delivery of a building or civil engineering object. The selected attributes must relate to both the design or production phase, the usage phase, and the end-of-life phase. In this way, data is recorded that is equal to reality, the as-is and as-built instead of the as-planned and as-developed of a building.

3. 10. REFERENCES

Scientific references

George Akerlof, The Market for Lemons, 1970.

Elma Durmisevic Design strategies for reversible buildings

URL: [https://www. bamb2020. eu/wp-content/uploads..., 2019]()

Elma Durmisevic Circular economy in construction design strategies for reversible buildings

BAMB, Netherlands. [Online] Available at: bamb2020 ..., 2019

EU H2020 BAMB-Buildings as Material Banks Project (Durmisevic, 2006), (Durmisevic, 2019).

Examples from the UK Green Council document: Insights on how circular economy principles can impact carbon and value

Design for flexibility

1. **JLL Office Fit-out:** 90% of the floor plate is reconfigurable with fixtures and furniture reconfigured or demountable. Minimizing constructed cellular spaces created an active workplace design without internal partitions. This resulted in, compared to a business-as-usual layout:
   a. 17% upfront CO_2 savings through design of materials and products by adopting an open plan office design approach, reducing the need for internal partitions.
   b. 23% upfront carbon savings because of reusing MEP (mechanical, electrical, and plumbing) equipment where possible and designing MEP materials and products as needed by adopting an open office design approach by using 35 fewer fans.

Design for assembly, disassembly and repairability

1. **Roots in the Sky:** Bolted structural connections are given priority over welded connections where structurally and technically feasible. This allows the primary steel material to be reused in future developments. Assuming a 50% recovery rate, this measure has the potential to save approximately 3,500 tonnes of CO_2 on future developments.
2. **Holbein Gardens:** New bricks laid with lime mortar; this can be cleaned so that the bricks can be dismantled at the end of their life: Lime Culture is estimated to have around 20% lower CO_2 emissions than cement production; lime mortar will also absorb CO_2 during the hydration process and become carbon neutral over time.

Standardization combined with off-site methods that reduce waste can reduce carbon up front. But standardization in design could increase carbon if not applied carefully and strategically. Examples:

1. **The Forge:** Using a Platform Design for Manufacture and Assembly (P-DfMA) means the project is on track to achieve a 25% embodied carbon reduction upfront compared to a typical new build baseline. Standardized products increase site productivity and reduce construction time, leading to a reduction in site emissions.
2. **80 Charlotte Street:** Prefabrication of the façade with prefabricated modular plant and other structural elements (pipes and ceilings) resulted in reduced waste, construction impact and on-site labour. This also saved construction time.
3. **JLL Office Fit-out:** Standard size materials implemented to minimize construction waste; along with design-out waste, there was a 14% upfront carbon saving compared to baseline due to transportation of less materials, products and waste, as well as less energy required on-site due to fewer materials and products installed.
4. **Blackrock Street:** Using timber and pre-insulated external wall panels and floor cassettes in a 'flat pack' Modern Methods of Construction (MMC) approach, the building was completed in a matter of days. There was a reduced carbon impact by using timber. It was also cheaper than traditional manufacturing.

Using low impact materials can result in buildings having a lower LCA than renovating the existing building. Examples:

1. **The Enterprise Centre:** Local natural materials (Norfolk flint), hemp fabric, Sonaspray, Warmcell, clay board, locally sourced timber frame and straw thatch cladding, solvent free paint, linoleum, linseed and hessian matting on recycled glass screed: overall the project embodied 65% less carbon than a conventional higher education building (at the time).
2. **Blackrock street:** Using wood as the primary building material saved 102 kg CO_2 e/m² (including storage).

Using recycled material in the cement can lead to lower initial carbon.

1. **The Enterprise Centre:** 70% GGBS (Ground-granulated Blast-furnace Slag) in the concrete gave an embodied carbon reduction of 62% compared to typical cement concrete.
2. **1 Triton Square:** Replacing an average of 65% cement with GGBS delivered an upfront embodied carbon saving of 665TCO_2 compared to 30% PFA (Pulverised Fuel Ash).
3. **The Forge:** GGBS 50% in substructure and 40% in superstructure delivered a 40% carbon reduction in the substructure and a 22% carbon reduction in the superstructure compared to typical cement concrete.
4. **Cambridge Avenue:** Recycled concrete specification saves 200tCO_2 e (63kgCO_2 e/m²).

Using recycled paint can lead to lower pre-carbon content.

The Entopia Building: 165 litres of paint (25% of the paint used) contained 35% recycled paint, a saving of approximately 10% embodied carbon compared to a comparable product.

Using recycled flooring can lead to lower initial carbon.

1. **Timber Square:** Reclaimed raised access floors have approximately 20% more carbon than new.
2. **80 Charlotte Street Fit-out:** Recycled content in carpet saved 67kg CO_2 e/m² of carpet area (22tCO_2 e) than a less environmentally friendly option from the same manufacturer.

Using recycled glass can lead to lower initial carbon.

The Burrell Collection: Using a closed loop glass recycling approach, over 16 tonnes (over 16%) of glass were processed into cullet to produce new architectural glass; saving 5 tCO_2 e.

Using recycled plastic can lead to lower initial carbon.

Blackrock Street: 100% recycled plastic drainage, formwork and separation joints reduced the need for concrete, saving 17 tCO_2.

Designing for waste is an easy win for carbon reduction, although it can be challenging to quantify. Designing for waste is closely linked to designing for flexibility and adaptability and can often aid disassembly and repairability, particularly for components or materials that are subject to changing tastes (e.g., Cat A or B facilities where the tenant will make significant changes to suit their style)

1. **The Entopia Building:** Avoided finishes on raised access floors to reduce embodied carbon; galvanised steel surface floor cleaned and exposed in some areas to reduce embodied carbon; (this is linked to re-use of original floor - Re-use of existing raised access floor saved 32 kg CO_2 e/m² (or approximately 85,000 kg CO_2 total) compared to using new raised access floor panels).
2. **80 Charlotte Street Fit-out:** The overall design minimises finishes where possible, using exposed ceilings with acoustic panels and aluminium clad exposed services – saving 346tCO_2 e compared to a suspended ceiling.
3. **JLL Office Fit-out:** Material Savings, Exposed Services Design avoided the use of a suspended ceiling, which combined with an acoustic internal vault spray to provide acoustic comfort. This delivered a 66% carbon saving compared to the fit-out housing due to low carbon flooring products, exposed ceilings, and the reduced number of internal partitions, which required additional finishes.

Shortened construction programs have the potential to reduce site impact, which may be achieved through standardization:

1. **Timber Square:** Dry construction techniques, minimising wet site managing e.g., raised access floors with minimal screeds. Minimising internal materials e.g., eliminating a full suspended ceiling. Erith carried out a pre-demolition study to investigate how recycling demolition and excavation materials could be maximised: the impact on the building was reduced by around 50% compared to a typical office.
2. **The Forge:** On-site production reduces on-site material waste.

4.

THE TRANSFER OF RIGHTS TO MATERIALS

By linking a property right to each material (blockchain registration), these rights can be given to a different owner. This provides the strategic choice for the tripartite division of land, building, material and can lead to new choices in dealing with materials, because materials in buildings can then also get a different (specialized) owner separately from the building. In this way, the future reuse of materials can also be arranged in advance in the form of contracts, including the issue of liability if something goes wrong with the materials.

Within the **Digital Deconstruction** project, a connection has been made between the Digital Materials Database and the Euthereum blockchain using two APIs, or connection parts between the database and the blockchain. These APIs are accessible via the Digital Materials Database. It gives the owner of the data in the Digital Materials Database the possibility to add a hash to his information. This hash or blockchain ID fulfills the role of connector between the Digital Materials Database and the blockchain and is organized in an automated way.

4. 1. INTRODUCTION

The Blockchain Module in the Digital Materials Database Cirdax offers a tool that strengthens the use of the Digital Materials Database. It is only effective if it can be used in combination with a Material Passport. Each Material has its own Material Passport, which gives this material its identity. The identity can be verified by registering the ownership of the passport in the blockchain, which also gives the possibility to see that registration as a property right at the time of registration. The blockchain registration serves as a property right that is also included in the material passport by means of its hash, i.e., the blockchain identity of the material passport.

The blockchain registration establishes ownership rights on the materials. Ownership rights give us the opportunity to link these to other rights, such as CO_2 rights, or to sell these rights to other stakeholders. The combination of materials with an identity, the verified blockchain registration and the characteristics of ownership rights, give us the opportunity to link materials to marketplaces and future contracts, because the immutable nature of information in the blockchain can also manage issues such as liability and duration. We always know who owns the materials. This is particularly important if we want to check over time who owns a material. In this way we can also organize an important task about the circular requirements for materials. Both in terms of delivery and the quality of the materials in the future. See also paragraph 2.10 under 4, in which we have given a description of factor time within the process of circularity of the built environment.

4. 2. INPUT

To organize the blockchain registration, the following inputs are required:

1. The material passport of each material stored in the Digital Materials Database
2. The server infrastructure for the APIs between the Digital Materials Database and the Ethereum Blockchain.

4. 3. PRODUCTS AND SERVICES

The blockchain registry gives each material a property right, which can be used to organize contracts, liability, track-and-trace capabilities, and any other information characteristics to use as a legal framework for the reuse of materials.

4. 4. METHODS, TECHNIQUES, TEMPLATES, AND INSTRUMENTS

For the allocation of ownership rights on materials, the Ethereum blockchain is used, combined with the digital materials database. A manual is available to guide the user through the blockchain registration of material passports.

4. 5. RESULTS

An important topic for strategic material use is the materials in a building itself without having to remove them immediately. In a classical way of thinking about materials, these materials cannot be used as an alternative and are of no value. However, by linking a property right to each material (blockchain registration), the property rights or options on the property rights can be given to a different owner. This provides the strategic choice for the tripartite division of land, building, material and can lead to new choices in dealing with materials, because materials in buildings can then also get a different (specialized) owner separately from the building. In this way, the future reuse of materials can also be arranged in advance in the form of contracts, including the issue of liability if something goes wrong with the materials. In this way, there is a strong incentive to prevent damage or waste of materials, including the social waste of the production of new materials in the form of CO_2 emissions during production.

The above option fits into the strategy of an organization and other real estate owners in the field of circularity and is organized using the Digital Materials Database and the Blockchain module. This can lead to different strategies, which only become effective later. One of these strategies is to see products as a service (PaaS) (see also chapter 2). The costs and benefits of these activities are part of the organizational costs. The benefits of these activities are visible in advance in the proceeds from the sale of materials from buildings, or the method of circular construction of new construction.

4. 6. QUALITY FACTORS

A blockchain registry makes it possible and affordable to secure the ownership rights of materials. This solves quality problems caused by asymmetric information, as described by Akerlof in the Theory of the Lemons. The ability to track and trace material usage by using the combination of the digital material database and a blockchain registry also helps with this quality and ownership problem.

4. 7. PROCESS ACTIVITIES

Within the **DDC** project, a connection has been made between the Digital Materials Database and the Euthereum blockchain using two APIs, or connection parts between the database and the blockchain. These APIs are accessible via the Digital Materials Database and form a separate chapter in this database. It gives the owner of the data in the Digital Materials Database the possibility to add a hash to his information. This hash or blockchain ID **fulfills** the role of connector between the Digital Materials Database and the blockchain and is organized in an automated way. The manual for the Digital Materials Database and the Blockchain modules shows how this works. With access to the Digital Materials Database, everyone can also perform the blockchain registrations.

4. 8. QUESTIONS AND ANSWERS

There have been no questions asked by users of this manual about this chapter yet.

4. 9. COMMENTS

The following comments may be added to this chapter.

1. Interoperability and Linked Data in Material Passports (from CB23)

If a material passport can be defined as the combination of different pieces of data with different origins (product data, usage data, data on availability for reuse, etc. but also associated information models), then it is necessary to be able to smoothly connect this heterogeneity of data. By means of independent standards in software applications, the long-term interoperability between different digital systems of various stakeholders can be guaranteed. The main requirement for digital systems for creating and managing a material passport is therefore the possibility of being able to always exchange data according to such 'open' standards.

Interoperability and linked data in the underlying ICT infrastructure about material passports ensure effective and above all efficient collaboration in the chain of reusable materials. In order to keep the content of an exchanged material in a passport dataset, including the external product data, irrefutably verifiable and to protect it against data loss, it is obvious to consider the use of 'ledger systems' such as a centralized ledger (e.g. government administration) or distributed ledger systems (such as blockchain) combined with dataset hashing.

To prevent data loss, for example due to the temporary loss of an online dataset at the primary source, copies of the dataset can be kept. The technical implementation of ledger systems and measures against data loss thereof are not included in the CB23 documents but have been realized in the **Digital Deconstruction** project.

2. Responsibility and liability of building materials products (from CB23)

Producers play a key role in developing product performance for subsequent cycles of product use. For both future reuse (to maintain the value of products for subsequent cycles), the use of secondary and biobased materials (to maintain material stocks), the reduction of the CO_2 footprint, and to protect the environment.

An obligation via an Extended Producer Responsibility (EPR) as it already exists in other sectors, should also be able to be introduced for construction products. And could be implemented using Blockchain registrations linked to a material passport.

Such an EPR for producers should cover:

- **Return guarantee:** the manufacturer provides a return guarantee at application and material level. In this guarantee they state that the product will be returned and the conditions under which it will be returned.
- **Detachable details:** the manufacturer provides details so that the product can be detached and is suitable for reuse/high-quality recycling.
- **(De-/re) assembly manual:** this manual explains how to install the product so that it is suitable for reuse/high-quality recycling in the second cycle.
- **Maintenance instructions:** this specifies the building owner's obligations to extend the lifespan by keeping the product in good condition.
- **Materials passport/BIM model:** manufacturer ensures that data is available for future use.

Furthermore, requirements can be included in specifications for buildings that products and/or producers of building materials should meet. The following points can be considered:

- The product must have been evaluated in accordance with the circular performance and must have a KOMO quality declaration and KOMO certificate with product certificate.
- Certain percentages of secondary material based on options suggested by the sector.
- A certain degree of recyclability based on options proposed by the sector.
- The manufacturer must have an LCA of the product in which scenarios for future reuse have been investigated. For the most efficient scenarios (leading to a lower MKI) the manufacturer must provide relevant performance requirements.
- The manufacturer must provide an efficient solution for recycling construction and demolition waste from the product and demonstrate this waste in a high-quality manner. The aim is to maintain its own cycle.
- The manufacturer must issue a take-back certificate for the project.

4. 10. REFERENCES

Scientific references

Guidelines Passports for construction Part 2 + 2 Working agreements and substantiation for passports in a circular construction sector Platform CB'23 June 2022

References within projects

1. Examples from the UK Green Council document: Insights on how circular economy principles can impact carbon and value

Technology-based products can result in lower upfront costs for owners to pass on to tenants, or financial savings with lower bills and lower operational energy consumption:

- **eLight:** Cost savings for consumers through lower operational energy costs: £19,841 for one school based on comparison with bills before installation of modern technology. Lower upfront costs for developers
- Considering PaaS at this early stage of a build-to-sell project will allow for efficient integration, which is more effective than reactively installing new kits and contracts after the building has been sold. Free repairs and maintenance for high-end interior products
- **Ahrend:** Free repair, for an investment of €45,000 in the working environment, with an estimated saving of approximately €6,000.

SOCIAL VALUATION OF REUSABLE MATERIALS

The result of the social valuation of a material is the representation of the actual value of a registered material in a digital materials data base.

When making a social valuation of the materials in a real estate object, the following activities are involved:

- From Chapter 3: Inventory of the materials in a building, including properties, removability, and toxicity.
- Select an "embodied carbon emissions" standard.
- Collect and record the "embodied carbon emissions" of a material. D.
- Collect and record market prices of CO_2 emissions (eex.com)
- Collect and register the CO_2 emission value in Euros on the market for tradable emission rights.
- Add up materials, embodied carbon emissions and market prices into a carbon emissions balance sheet, materials balance sheet and social materials balance sheet.

5. 1. INTRODUCTION

Reusable materials have both a social and a financial value. The social value of materials is broader than the financial value of materials because the social value also includes those qualitative benefits that cannot be directly recorded in monetary units. An example of these externalities is the value of saved CO_2 emissions that go hand in hand with the reuse of materials from a building because the reuse of materials avoids the realisation of new materials and the environment is not further affected.

Materials can only have a value if these materials can be used in an alternative way. This means that they can be detached without much damage and can once again provide a function in a real estate object with complete information for the buyer and seller. In this chapter, the social value determination of reusable materials is further explained and clarified.

5. 2. INPUT

To arrive at a social value assessment of reusable materials, the following input is desirable:

1. The different properties of a material.
2. The quantitative size of a material.
3. The degree of removability, that is, the alternative applicability of a material.
4. Limiting characteristics of a material for reuse.
5. The ownership or blockchain registration of the materials.
6. Calculation methods relating to the *"embodied CO_2"* of materials.
7. Materials valuation methods.
8. Market information about the alternative price of materials in a market.

5. 3. PRODUCTS AND SERVICES

The first product that serves the social valuation of the materials in a building is the CO_2 balance of a building. This product provides the sum of all CO_2 savings that are realized with the reuse of materials in a building. The CO_2 balance of a building combines the following elements, namely:

1. The size of each specific material in a building
2. The ability to remove the material undamaged.
3. The *"embedded CO_2"* in the realization of new equal material at a standard weight

4. Multiplying the actual weight of the materials with the *"embedded CO_2"* for each material.
5. The sum of all multiplications of all materials for the registered (in blockchain) owner in saved CO_2 in alternative use.
6. The market value of this CO_2 saving by multiplying the amount of CO_2 saved by the trading price of CO_2 rights, in accordance with the European Trading System of CO_2. (See eex.com; price of CO_2 rights as of May 15, 2025 = € 70.11)

The second product that serves the social valuation of the materials in a building is the Materials Balance of a building. This product provides the sum of all direct market values of the materials in an alternative application, such as can be obtained on a marketplace.

The Material Balance of a building combines the following elements, namely:

1. The size of each specific material in a building
2. The ability to remove the material undamaged.
3. The price of a material on a reusable materials market
4. Multiplying the current weight of the materials by the market price for each material in Euros
5. The sum of all multiplications of all materials for the registered (in the blockchain) owner in Euros.

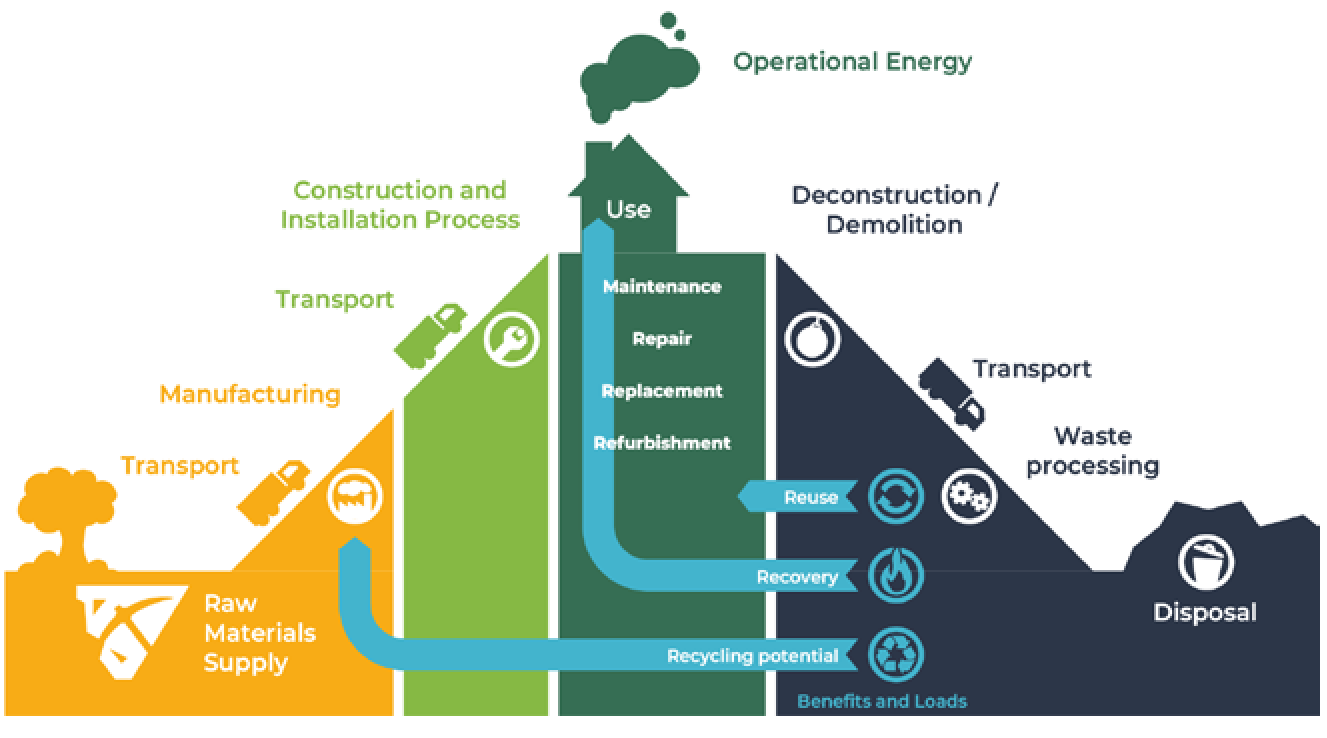
The third product that serves the social valuation of the materials in a building is the Social Materials Balance of a building. This consists of the sum of the CO_2 balance and the Materials balance of the building.

5. 4. METHODS, TECHNIQUES, TEMPLATES AND INSTRUMENTS

Within the Digital Materials Database, templates are available with which the calculations of the value of the products can be filled in. These calculations are based on the inventoried materials. Within the templates, all the basic data mentioned in paragraph 5.3. can be filled in. The calculations can also be made on an Excel form, if the correct basic data is also available.

The *"embodied"* CO_2 savings can be collected using various databases and reflect the following components for each material, as shown in the figure below:

One of these databases is the ICE database, built by the University of Bath in the United Kingdom. The CO_2 calculations that are linked to the RBIM model, as well as the Digital Materials Database use the ICE database. The calculation of the embodied environmental value assessed by RBIM is also based on the assessment of the effort required to restore material and the repair efforts required for its reuse. The Environmental Embodied value reflects the potential avoidance of CO_2 emissions, waste, and energy, as well as potential material reuse.



In France, when calculating the CO_2 savings for an old building, the LCA methodology established by the French government using the INIES database and the FDES is used. The CO_2 savings are estimated equal to the CO_2 emissions of a new product that we would have to buy if the material could not have been reused. A methodology (for Bordeaux Metropole) has also been developed by Nobatek to evaluate the effects of reuse approaches.

5. 5. RESULTS

The result of the social valuation of a material is the representation of the actual value of a registered material in a digital materials database, which is also provided with a right of ownership by means of a blockchain registration. The sum of the various property rights of materials in a building can be summarized in the material balance of a building. If the CO_2 value of the saved CO_2 emissions is added to this, the sum of this material and CO_2 balance forms the Social Materials Balance of a building.

5. 6. QUALITY FACTORS

The calculations of the Social Value of the materials in a building are based on a transparent quality of the materials. However, this can encounter problems in practice, for example because of the presence of toxicity in certain materials. In that case, materials cannot be used as alternatives, even though they can be separated.

Another factor that influences the social value of materials is the presence of a market for reusable materials. Markets for reusable materials are currently dependent on the access of buyers and suppliers in a certain geographical region to this market, and on the transparent quality of the materials demanded and supplied. The more transparent the quality, the more buyers and suppliers will value this market, which will ensure that the value of new and reusable materials of a specific type will approach each other.

The prices of reusable materials in a building on a market are the product of both the intrinsic value of these materials, and the processing and treatment costs of these materials to give them an alternative destination. In business economics terms, the value of a reusable material in a building will be lower than the value of a freely available material on a market, because in the latter the various handling costs are also included in the market price.

However, if the saved CO_2 through reuse can be included in the pricing of reusable materials, this increases the value of the materials in a building. If the CO_2 value of a material is equal to the handling costs of a material to make it freely usable again in an alternative use, the market value of reusable materials can be set equal to the market value of primary materials, provided by a public marketplace (wholesaler for building materials).

For the time being, the saved CO_2 through reuse cannot be converted directly into Euros. However, calculations can be made as if this were possible. In addition, research has been requested into the size of the handling costs for the removal of materials, so that they are reusable with the desired quality. Research into the purchase prices of reusable materials by *"harvesters"* of building materials is another important component, which amounts to the quality of prices on markets for reusable materials in buildings.

5. 7. PROCESS ACTIVITIES

When making a social valuation of the materials in a real estate object, the following process activities are involved:

1. From Chapter 3: Inventory of the materials in a building, including properties, removability, and toxicity.
    a. Use RBIM output and the results of the different **SUM4Re** tools to elaborate the most desirable reuse options for a given circularity performance target of the project
    b. Use the Digital Materials Database to estimate the embodied CO_2 of the deconstructed and reused products.

2. Select an *"embodied carbon emissions"* standard, as described in Section 4 of this Chapter.
   a. Compare values with the project objective.
   b. Environmental criteria may include: quantities of products from the existing building reused and/or recycled, reduction of waste, avoided new products, reduction of transport, avoided Kg CO_2 emissions.
   c. Use existing LCA tools (ex SimaPro), and/or tools proposed by marketplaces (ex Cycle-Up), and/or tools from **DDC** (RBIM, Cirdax).
3. Collecting and recording the *"embodied carbon emissions"* of a material.
4. Collecting and recording market prices of CO_2 emissions (eex.com)
5. Collecting and registering the CO_2 emission value in Euros on the market for tradable emission rights.
6. Adding up materials, embodied carbon emissions and market prices into a carbon emissions balance sheet, materials balance sheet and social materials balance sheet.

5. 8. QUESTIONS AND ANSWERS

The following questions have been addressed in projects on this topic. Each question has an answer.

Question: Are CO_2 savings through the reuse of materials a strategic objective of your organization?

Respondent 1: Yes

Respondent 2: We want to save 50% CO_2 between 2015 and 2030. Reuse is therefore a very good way to achieve our goal.

Respondent 3: Yes, we want to reduce our CO_2 emissions and so reuse is a very good way to achieve our goal.

Question: What benchmark for CO_2 savings through reuse of materials do you currently use?

Respondent 1: The design team makes the calculation.

Respondent 2: Assessment with the DGNB approach

Respondent 3: This is done as determined when drawing up the demolition inventory (which is mandatory for a Belgian permit application).

Respondent 4: External partners do the calculation.

Respondent 5: The CO_2 savings are calculated using the LCA methodology established by the French government. That is why we use the INIES database and FDES. This methodology is mandatory for all new buildings. When we calculated the CO_2 savings for an old building, we used the same methodology. The CO_2 savings are estimated to be equal to the CO_2 emissions of a new product that we would have to buy if the material could not have been reused.

Question: Reducing the amount of plastic packaging can reduce supply and choice. This can potentially have a knock-on effect as products are damaged by incorrect packaging, creating more waste.

Answer: Specify manufacturers with packaging take-back services.

5. 9. COMMENTS

The following comments can be added to this chapter.

The Environmental Performance of Buildings and Totem

When designing and realising a building in the Netherlands, the Environmental Performance of Buildings (MPG) must be calculated. The Water and Road Construction sector in the Netherlands uses the Environmental Cost Indicator (MKI) for this purpose. In Belgium, the TOTEM instrument is used for this purpose, with the same objectives as the MPG in the Netherlands. The MPG and MKI are based on the Determination Method for the Environmental Performance of Buildings and the associated National Environmental Database (NMD) with the environmental performance of products.

The determination method provides for the consideration of materials to be reused. Model rules have been included for this. However, there are several points of attention when calculating the environmental performance of the building. These also apply within certain margins when drawing up frequently occurring products to be reused:

1. The original producer is unknown. It is complex to relate materials released from demolition to the 'initial or most representative product in the NMD', which the Determination Method assumes.
2. There is a great deal of variation in the numbers and quantities of materials released. In the case of small series or individual products released from demolition, it is complex and expensive for an individual demolition contractor to perform the calculation of the score.
3. Each product to be reused is unique and there are no recipes for making an LCA analysis. Many different flows are released from a demolition job. An average job quickly involves forty varied materials, for which a calculation would have to be made.

The above arguments assume that the environmental value of materials is derived from the history of these materials. However, this is incorrect, because according to the usual economic theory these are *"sunk costs."* Sunk costs are not relevant for a cost-benefit analysis about circularity, as advocated in this manual. However, it does concern the production of new materials, which is prevented by reusing materials. This involves opportunity costs, namely the trade-off between using existing or new materials, or in other words, making a material disappear and the necessary new production, versus reusing materials, including the costs of processing, and repairing.

Other social values

In the various British projects on reducing material use and thus also reducing CO_2 emissions, many other social values are also addressed, which can be included in a social cost-benefit analysis. These are not all easy to quantify, as is the case for CO_2 savings, but can be included in a social cost-benefit analysis, so that their value is also visible.

This concerns the following examples:

1. Circular principles have contributed to numerous sustainability certifications and accreditations such as BREEAM and WELL
2. Many of the case studies were conducted as pilot projects to inform the clients' own sustainability strategies.
3. Access to financing benefits only available to projects with explicit sustainable benchmarks and ambitions
4. Value of preserving the historic structure and character of buildings
5. Job creation (e.g., pop-up factories for refurbishing and processing recovered materials), measured by the number of jobs created.
6. Reduced air pollution (PM 10, PM2.5) and local congestion, measured by total mileage savings due to reduced transportation emissions from fewer materials/transport required.
7. Training opportunities for staff or tenants.
8. Social value by sharing materials with charities and schools.
9. Marketing benefits for developers who want to reuse buildings in the future due to the carbon costs of new construction.
10. Ability for residential buildings to accommodate changing family sizes and structures because of reconfiguration.
11. A long lifespan may mean that a building is less likely to be demolished after 20 or 30 years due to changing tastes, which can increase the social acceptance of the community.
12. Increased safety on site through prefabricated components that enable easier installation:
13. Supporting local suppliers
14. Improved health and safety of the manufacturing and demolition process and improved community relations
15. Low impact materials can contribute to green rating schemes and increase health and well-being.
16. Pleasant spaces for residents are designed with well-being in mind.
17. Using low-impact materials can lead to benefits for improved health and well-being.

5. 10. REFERENCES

Scientific references

Embedded CO_2: The University of Bath's ICE database - *https://circularecology.com/embodied-carbon-footprint-database.html*

References within projects

The stones in Ettelbrück station have already been donated to the INPA (Institut National du Patrimoine et de l'Architecture). The INPA wants to reuse the special stones to rebuild the same station in another location. The stones come from a quarry that has been closed for a long time, which makes the stones very rare and therefore of great historical value. Including the saving in CO_2 (including value) by reusing these stones.

6.

INVENTORY OF THE COSTS OF SERVICES DURING THE DEMOLITION OF A BUILDING

The result of determining the costs of sustainable demolition is a quantitative interpretation of the various aspects of sustainable demolition of a building.

When making an inventory of the costs of services during the demolition of a building, the following process activities are discussed:

- Choosing a specific cost methodology.
- Completing this cost methodology with the data already collected from inventories.
- Supplementing missing data by requesting this data from suppliers in the field of demolition.
- Preparing the cost overviews based on this methodology..

6. 1. INTRODUCTION

For every real estate object that is given an alternative destination, certain costs will be incurred. This also applies to the costs of services for the demolition of a building. In this manual, the costs of services for the demolition of a building, or the alternative use of the materials in a building, are kept separate from the value of the materials. In this way, both the costs and the benefits of the demolition of a building can be given substance in a transparent and appropriate manner, and costs and benefits are not necessarily mixed with each other.

Demolition of a building also ensures that a building, the land on which the building stands, and the materials in the building can be given an alternative purpose. The added value of demolition and the associated costs must therefore be considered in terms of both the alternative revenue from services that a new building realises, the change in value of the land as a result of the alternative purpose of the land after the demolition of the original building, and the value that the materials have in an alternative application.

This also means that the costs of demolition cannot be directly attributed to one of the possible proceeds of demolition, but that there must be a weighted average, depending on the own choice of cost allocation. A subject that is discussed in the next chapter of the manual. This chapter concerns the mapping of the various costs associated with demolition, both in a traditional way and in a sustainable way aimed at reusing available materials. In this way, the alternatives are also mapped out and can be part of the weighing issues in actual decision-making.

6. 2. INPUT

To determine the costs of sustainable demolition, the following data is required:

1. The data of the building in terms of size, construction, and all other aspects of a building that can be read from drawings of the building.
2. The inventory of the materials in the building with all available instruments.
3. The removability of the materials in the building.
4. The types and extent of services provided by a demolition contractor in relation to the stripping, removal, dismantling and demolition of the various elements and materials in a building, as well as the preparation for this.
5. The logistical costs of removing the materials in terms of transportation and storage

6. 3. PRODUCTS AND SERVICES

The products and services available to calculate the costs of demolition are:

1. A methodological costing approach applied to the costs of demolishing a building.
2. The different cost prices of tools, machines, resources, and workforce.

6. 4. METHODS, TECHNIQUES, TEMPLATES AND INSTRUMENTS

The primary focus of the techniques is a methodology that maps out the various costs of demolition. For example, resulting from a demolition plan, in accordance with the requirements in a specific country. For the Netherlands, we are talking about BRL SVMS-007 and the Verification Regulation Circular Demolition Project (VCS). This may also involve templates that can be used to compare the costs of traditional demolition and sustainable demolition, so that the marginal costs of demolition become visible based on the nearest alternative to this sustainable demolition, namely a traditional method of demolition. These marginal costs can then also be compared with the marginal revenues of sustainable demolition, as presented in Chapter 3.

The templates and instruments for determining the costs of demolition are often included in the products and services, which make the costs of demolition transparent. Examples of demolition companies or in its simplest form an applied Excel form can serve here.

6. 5. RESULTS

The result of determining the costs of sustainable demolition is a quantitative interpretation of the various aspects of sustainable demolition of a building, so that these can be placed in a framework for consideration. This framework for consideration is discussed in Chapter 7 (Decision-making).

6. 6. QUALITY FACTORS

The most important quality factor in this chapter is the correct use of cost accounting and cost allocation using business economic methodologies that are appropriate within the standards for controllers' working methods. Given that the correct information has been provided in inventories.

6. 7. PROCESS ACTIVITIES

When making an inventory of the costs of services during the demolition of a building, the following process activities are discussed:

1. Choosing a specific cost methodology.
2. Completing this cost methodology with the data already collected from inventory or from previous projects.
3. Supplementing missing data by requesting this data from suppliers in the field of demolition.
4. Preparing the cost overviews based on this methodology.

6. 8. QUESTIONS AND ANSWERS

There are no questions or answers for this chapter yet.

6. 9. COMMENTS

The following comments can be added to this chapter.

Comment 1: The BRL SVMS-007 and the Verification Regulation Circular Demolition Project (VCS) stipulate that a plan is made of the demolition process. The released materials are inventoried during the demolition process. In doing so, it is assessed whether the released materials meet the specifications. After the demolition, a materials account is drawn up according to the VCS. A certification body verifies this materials account. This makes it demonstrable how much material of which quality has been released from a project. To reduce time and costs in the future, it helps if more insight is gained into the history, quality, and removability of products during demolition. This can be done by drawing up a materials passport of a building and the products used (see also CB'23 Guideline Passports for construction).

Comment 2: Quality assurance of products to be reused is necessary to remove uncertainties or unfamiliarity among designers, contractors, quality assurance officers or competent authorities, and to demonstrate that the requirements are met in a new application. A demolition contractor must first conduct a quality assessment. The assessment method is based on the process, the material in question and the desired application. The first quality assessment must take place while the building element is in use in the 'old' situation. After all, the quality can be demonstrated in the use phase.

6. 10. REFERENCES

Scientific references

There are no scientific references included in this chapter yet.

Effort

What efforts are needed to produce and present the information from your instrument (several alternatives are possible)?

- Laber
- Capital
- Tools
- Logistical efforts
- Access to information (carriers), such as databases

Ease

How easy or difficult is it for an average worker to use your tools?

- Easy without training
- Quite simple
- Easy after training
- Difficult
- Complex with a lot of experience

Costs

What costs do you charge when using an instrument?

- Manpower per hour (open answer)
- Purchase price of the instrument (open answer)
- Instrument per hour/period (open answer)
- Logistics costs per hour/activity etc. (open answer)
- Information costs per hour/activity/period (open answer)
- Other costs (open answer)

References within projects

Within the **SUM4Re** project, questions were asked about the costs and efforts associated with the various instruments. Below is an overview of the results of these questions.

iMMS Lidar

Efforts: Capital; Tools; Labor.

The main limitation of LiDAR is its price, which can reach up to €30,000. In contrast, the AR HoloLens costs €5,000 but has limitations in terms of the quality of the data generated and the range. In addition, generating a 3D model is no longer an automatic process and can require a lot of time and specific software.

Ease: Quite easy.

The equipment is easy to use and requires only a few instructions, but we strive to make the environment more user-friendly.

Costs: Purchase price of the instrument; Manpower per hour.

GPR-ECT

Efforts: Labor; Tools.

Ease: Easy after training.

Costs: Workforce per hour; Instrument purchase price.

FOS

Efforts: Labor; Capital; Tools.

Work: The installation of the sensors requires specific training for the workers who install these sensors. A preliminary analysis of the structural element is also required for designing the monitoring plan. Capital: The purchase price of the fiber optic sensors and data acquirers is relevant, also considering licenses related to the software costs. Tools: In addition to the required installation of the sensor tools, the software tools involved are also important.

Ease: Difficult.

The sensor installation can be easily conducted but requires a preliminary monitoring plan and the interpretation of the obtained data results, which must be analyzed by a structural engineer.

Costs: Purchase price of the instrument; Information costs per hour/activity/period; Manpower per hour.

It is difficult to estimate the exact costs of using the system as it is ad hoc for each scenario

XRF

Efforts: Capital; Labor; Tools; Logistical efforts; Access to information (carriers), such as databases.

Costs: Purchase price of the instrument; Logistic costs per hour/activity etc.; Instrument per hour/period; Personnel per hour.

The main costs for both are the calibration standards to ensure that the measurements are performed correctly. Also, the logistics to go to the location and perform the measurements on site and the annual maintenance of the instrument are required. The cost of the instruments can also affect the potential samples that can be analyzed, as higher costs can potentially analyze a larger amount of samples.

MFT

Efforts: Labor; Capital; Resources; Logistical efforts.

The scanners are heavy and bulky, but passive.

Ease: Quite easy.

You just need to know where to set the location and how to position the scanners.

Costs: Instrument per hour/period.

AHS

Efforts: Tools; Labor; Capital.

Hire skilled personnel to further develop the technology. Capital: To improve technological readiness and bring the product to market (currently a research prototype and not yet a product). Resources: AI/machine learning/machine vision tools.

Ease: Complex with a lot of experience.

As mentioned in previous answers, we currently have a research prototype that can only be operated by skilled personnel.

Costs: Difficult to estimate because the prototype is still far from a product

7.

DECISION MAKING

The result of the work in this chapter is the decision to demolish a building traditionally or sustainably.

In the actual decision-making process about the alternative use of a building and the materials in this building, the following process activities are involved:

- Realizing the (social) costs and benefits.
- Recalculate future costs and benefits at their present value.
- Assigning the correct costs and benefits to the decision to be taken.
- An assessment of the completeness and quality of costs and benefits.
- Selecting a decision model.
- Making the decision.

7. 1. INTRODUCTION

The various qualitative costs and benefits associated with the alternative use of materials can be added together after filling in the various quantitative and financial values of the materials, so that there is a conclusive cost-benefit analysis. For this it is also necessary that the various costs and benefits are also placed next to each other in a time framework in a correct manner, including the correct discount rate to make future benefits and expenses comparable with the costs and benefits that arise in the present.

In addition, it is important to compare all demolition costs with all demolition revenues, because demolition work not only contributes to the alternative revenue of the materials, but also to the freeing up of the land on which a building stands for the alternative use of this land, and also to the added value of the alternative destination of the building in terms of residential, office, retail and other services.

The final sums of costs and benefits then form the basis for a decision on how the materials in a building or the building itself will be given an alternative purpose.

7. 2. INPUT

To decide on the method of demolition, the following input is necessary:

1. The economic benefits of reusing materials, soil, and the function of a building (Chapter 5)
2. The social benefits of reusing materials, soil, and the function of a building (Chapter 5)
3. The costs of demolition (Chapter 6) according to the chosen cost methodology.
4. A discount rate for discounting future costs and benefits.
5. A methodology for allocating costs to benefits and making an integrated cost-benefit analysis.
6. Business economic information on the costs and benefits of traditional building demolition.
7. The Digital Materials Database stores information about the ownership of the materials, supported by the blockchain module and the (technical) possibility to reuse materials in the building, supported by the Reversible BIM module. The inventory process for entering information in the Digital Materials Database uses information provided by digital or 3D scanning, saving inventory time compared to manual inventories. The tools from **SUM4Re**, and GPR-ECT, FOS, XRF, MFT and AHS ensure that the quality of the materials is better visible. Information that is also stored in Digital Materials Databases. The Digital Materials Database therefore offers multiple forms of information that can be used for cost-benefit analyses.

7. 3. PRODUCTS AND SERVICES

The final product in this chapter is an integral cost-benefit analysis regarding the method of demolishing a building, so that a manager can decide. The product is in the form of a decision document.

7. 4. METHODS, TECHNIQUES, TEMPLATES AND INSTRUMENTS

To make an integral cost-benefit analysis for decision-making, the analysed costs and benefits can contribute to decision-making in two ways. The first compares all (integral) costs and benefits of a building in the field of sustainable demolition and enables a manager to decide based on this comparison of costs and benefits.

The second technique is based on a marginal cost-benefit analysis. This means that a manager's decision is made based on a comparison of the costs and benefits of a traditional demolition method with the additional costs and benefits of sustainable demolition. In this second technique it is important that business economic information regarding previous traditional demolition projects is available and usable for this marginal cost-benefit analysis.

The methodology for cost-benefit analyses for Circular Demolition can therefore be based on the following two comparisons, which distinguish between classic demolition and circular demolition or dismantling.

The equations are written in terms of costs and benefits:

1. K = O + Sk + Dk – Mk
2. C = O + I + V + Dc + R – Mc

The letters represent the following aspects of the demolition and/or dismantling process:

Sc: the costs of the circular services of a demolition company

Dc: the costs of removing and depositing materials that no longer have value and storing for reuse those materials that still have value.

R: the costs of processing the materials released from a building into new materials for reuse

Mc: the yield of materials from a circular demolition process.

The aim of the analysis is to determine what the above variables exactly embody in each situation. And which aspects can ensure that the extra efforts in a circular process also lead to extra benefits, so that the K > C, i.e., to the situation in which the costs of the classic demolition process are higher than the method of circular demolition/dismantling.

Or described the other way around, when a circular demolition process is of added value, on which an organization can determine its strategy in the field of building, land, and materials. Once the strategy is clear, it is also easier to initiate long-term investments in circular demolition and to use the associated tools, such as the Digital Materials Database.

The methodological explanation is therefore a basic framework within which the use of all **DDC** and **SUM4Re** tools can be placed, because without a clear goal the added value of the **DDC** and **SUM4Re** tools and all its functionalities cannot be properly evaluated. You do not know what you are evaluating it for.

7.4.1. Labor productivity in a decision-making perspective

Labor productivity, usually defined as the ratio of output to labor input, measures how efficiently labor is used to generate output (OECD, 2001). In the context of inventory counting, output depends not only on the effort of individual workers but is also influenced by other factors, notably equipment (capital) and skills. Labor productivity can improve through technological advances that increase efficiency or through skill development that enables workers to work more effectively. This paragraph examines the application of various tools aimed at replacing some of the manual labor with capital inputs. A Cobb-Douglas specification is used to capture both capital-labor substitution and diminishing marginal returns, which fit the empirical features of the inventory counting process:

$$P_{ij} = A_{ij} K_{ij}^{\alpha ij} L_{ij}^{\beta ij}$$

Where P the outcome of the inventory work is presented, A the technology level is shown, K And L the capital and labor inputs, where α and β represent the output elasticities, respectively, which capture the sensitivity of output to changes in each factor input. It is assumed that α and β < 1, indicating diminishing marginal returns to inventory, implying that while increasing capital or labor increases productivity, the incremental benefit of an additional unit of capital or labor contributes less to productivity as its quantity increases. Not all factor inputs are equally applicable to materials i and products j, indicating that some capital and labor improvements are more effective than others. A further distinction is made between information required for legal and regulatory standards, P_b, and information that improves marketability by informing potential buyers, P_y Each type of information has different relationships between factor inputs and outputs, with the P_b more capital-intensive because it requires more precise quantitative information (e.g., material strength, chemical composition) and P_y the more subjective judgments (aesthetic qualities, historical significance). This distinction is important for later analysis of how different equipment investments affect inventory results.

For circular construction, inventory serves as an intermediate process that provides ex-ante information, allowing for a more informed decision between demolition and deconstruction. The efficiency of inventory has both a direct and indirect effect on the degree of reusability of building materials. Directly, a higher inventory efficiency allows for more detailed information to be obtained without increasing input requirements. Indirectly, the information obtained allows for a more efficient deconstruction process, as it facilitates planning, optimizes deconstruction workflows, and ensures compliance with legal requirements for material reuse. This relationship can be formalized using a profit function that represents the trade-off between inventory costs and the economic benefits of different deconstruction strategies:

$$\Pi = \sum_{i,j} [\theta_{ij}(Y_{c,ij} - (0_{c,ij} + S_{c,ij})) + (1 - \theta_{ij})(Y_{d,ij} - (O_{d,ij} + S_{d,ij} + B_{d,ij}))] - 1$$

Where Π is the profit or loss of the deconstruction project, and θ indicates the proportion of materials deconstructed since demolition. Y, 0, S and B represent the material residual value, organizational costs, demolition work, and legal costs, respectively, while c and d refer to circular deconstruction and traditional demolition, respectively, and finally i represent the inventory costs. Y, 0, S and B are functions of the obtained inventory information, which means that improvements in P the directly affect the economic feasibility of deconstruction. Note that P_y the residual value most affects Y, while P_b the legal costs affect B. This distinction highlights the marginal profitability of different types of information: once the legal requirements are met P_b, additional information has limited economic value, while P_y its material desirability and resale value can further increase.

A questionnaire is being used to assess the productivity enhancing properties of these instruments. This is done by examining the instruments themselves, the types of labor and capital required for their operation, their applicability to different types of materials and products, and the limitations on wider application.

Labor productivity in SUM4Re

The use of iMMS, LiDAR, and AR scanners in the inventory process generates 3D point clouds, which can be digitally linked to various software tools, including those enhanced with AI. These tools allow for the addition of manual annotations to indicate the type and quality of materials, such as visible cracks or other damage. The main advantage of these scanners lies in their ability to provide precise measurements of entire rooms or buildings, which is beneficial for creating a digital representation of the structure. While the accuracy of the measurements is valuable, this information is only useful if it can be linked to individual materials and products, which require further processing and interpretation. A 3D point cloud by itself does not provide direct insight into the deconstruction or demolition process or the value of the individual materials and products.

The high cost of these technologies poses significant barriers to their widespread use in inventory. The LiDAR scanner, priced at approximately $30,000, provides high-quality results, but the cost may outweigh the benefits for certain applications. In comparison, the AR HoloLens, priced at $5,000, provides lower-quality results but is significantly more affordable. While both tools improve measurement accuracy, the time required to manually annotate the generated data is significantly longer than the time spent scanning itself. This raises the question of whether investing in a 3D model as a blank canvas upon which further information can be added is truly valuable for the purposes of deconstruction and demolition, especially given the time and effort required for data interpretation. Using a table-like format such as Cirdax, which can store material and product information, may prove equally effective with less capital investment. Furthermore, the 3D point cloud does not provide information about the chemical composition of the materials, nor about the measurement of the third dimension, such as wall thickness. This type of P_b information is relevant for performing calculations for legal standards. However, the outcome does provide P_y information because it gives customers an idea of what the material looked like in a previous situation. Finally, the measurement information is material i and product independent j, which means that the tool can be applied to all types of building materials.

Ground Penetrating Radar (GPR) is a portable tool used to scan surfaces, identify embedded materials such as reinforced concrete, and detect problems such as corrosion, moisture, and cracks. In the context of deconstruction, GPR primarily generates P_b information relevant to legal and safety assessments. It helps determine whether materials meet the required strength and safety standards for reuse, with an emphasis on the structural integrity of the material rather than its ability to be recycled or reused. This is important to ensure that materials are safe for use in new construction or deconstruction. Although GPR can scan a variety of materials, its impact is greatest on concrete, metal, and asphalt, where it detects the presence of embedded materials and wear. Pricing information about the GPR is not explicitly provided, but the equipment is supposed to be able to perform a significant assessment, like a LiDAR scan. Within minutes, a GPR expert can detect the reinforcement in a 25 m² concrete floor. Fiber optic sensing is a tool specifically designed for steel that can measure stresses and loads. It provides P_b information that helps assess the structural integrity of steel beams and reinforced concrete and their suitability for reuse. By measuring stress and removability, it allows for the reuse of entire building components instead of just materials, which provides greater sustainability benefits. However, its application is limited to specific segments, making effective scalability difficult. In addition, the technology is complex to use and both the equipment and software are expensive. GPR is faster and more versatile and can be applied to various materials, while fiber optic sensing offers higher precision for steel, allowing for the reuse of entire structural elements instead of just the material itself.

Inventory is a crucial step prior to deconstruction, as it informs important decisions about material reuse and the selection of appropriate tools. Without prior information, it is difficult to determine which tools to use, especially if the equipment is specific to certain materials or products. For example, it is difficult to assess the structural integrity of a steel beam if it is not physically accessible prior to deconstruction, as it cannot be evaluated for reuse until after disassembly. This increases the logistical and organizational complexity of material reuse, which increases costs $0c$. Although 3D point cloud scanning and GPR can provide valuable technological insights during the early construction or use phase of a building (such as determining renovation or maintenance needs), their usefulness during the deconstruction phase is limited. The information gathered with these tools is less applicable during the disassembly phase of the structure, as they are more useful for understanding the overall layout and condition of the building. In contrast, fiber optic sensing is more suitable for assessing structural elements during deconstruction, as it allows detailed evaluation of steel beams and reinforced concrete. The high cost of the instruments and the need for specialized training significantly reduce their economic feasibility for deconstruction projects. These technologies require significant investments in both equipment and expertise, which may not be justified given the limited scope of their application in deconstruction compared to their broader applications in construction, maintenance, or inspection. In addition, the time required to operate these instruments and interpret the results adds an additional layer of cost, making them less economically feasible for large-scale deconstruction projects where efficiency and cost-effectiveness are paramount.

7. 5. RESULTS

The result of the work in this chapter is the decision to demolish a building traditionally or sustainably.

To simplify the analysis and get this result, you can assume that in the classic scenario it is only about costs and that the material yield can be set to 0. In addition, you can assume that the organizational costs of both processes are the same, even if the lack of knowledge about circular demolition/dismantling temporarily causes differences in these organizational costs.

In a break-even analysis, the combination of equations 1 and 2 then looks like this:

1. Sk + Dk = I + Sc + Dc + R – Mc

In other words

2. Mc = I + (Sc-Sk) + (Dc – Dk + R)

Equation 2 states that the material revenues are equal to the costs of inventory I, the additional costs for services provided by the demolition/dismantling company, and the additional costs for depositing, processing, and storing the materials. The task now is to examine these costs and benefits more closely. In a marginal cost-benefit analysis, we would say that:

3. dMc = dI + d(Sc-Sk) + d(Dc-Dk+R)

This means that the change in revenues from circular demolition/dismantling must be equal to the (new) costs of inventory, the change in the costs of the services of the demolition/dismantling company and the change in the costs of processing, depositing, and storing the materials. In this way, costs and choices can also be linked, because in this way the alternative costs and benefits can be weighed against each other.

7. 6. QUALITY FACTORS

The availability, completeness, and reliability of all business economic information about a building and the material in a building is an important factor in decision making processes. Deciding with incomplete information is more the norm than the exception. The more complete and reliable the business economic information about the costs and benefits for the decision on sustainable demolition is, the better a decision based on an integral cost-benefit analysis is. The less the quality of information, the better to concentrate on a marginal cost-benefit analysis and derived decision making.

Another important quality factor concerns the available time for conducting all activities, as well as the time factor in general. With the latter we mean that costs and benefits can only be compared properly if they relate to the same time frame, so that costs in the present do not have to be compared with benefits in the future.

The quality factor time concerns the possibility to inventory suitable materials, as well as to find a buyer for these materials. By inventorying materials early, in accordance with the provisions in chapter 3, the transparency of the quality and availability of materials becomes clear. A demolition or dismantling company then has the preparation time and possibilities ready to remove the materials from a building without much damage to materials. If this time is not available, the quality of the demolition process is much lower and the damage to materials is much higher.

Secondly, the quality factor time relates to finding a buyer. The more time available, the more matching opportunities between the supplier and buyer of secondary materials can be organised. How much time is ideal depends on the effectiveness of the buyers network of materials for the property owner or the demolition company, or is related to an improved organisation of buyer and suppliers, for example by means of a digital marketplace (see chapter 12). The less time there is for matching, the lower the returns in a social cost-benefit analysis will be.

The quality of time can be improved by investing in advance in information about the materials in a building. This is done by inventory work, or by means of investments in the environment in which suppliers and demanders meet. In practice, we speak about a digital marketplace, where trading can already begin, while the materials are still in the building. A trade based on the ownership rights of the materials in a building supported by a material passport witf blockchain registration.

A final dimension with respect to time in a cost-benefit analysis concerns the discount rate used, with which future costs and benefits are offset against the present, or in other words, discounted. The advice for this interest or discount rate is to be linked to the discount rate for social cost-benefit analysis. In the Netherlands, this currently amounts to 2.25%.

7. 7. PROCESS ACTIVITIES

In the actual decision-making process about the alternative use of a building and the materials in this building, the following process activities are involved:

1. Realizing the (social) costs and benefits.
   - Use all data collected during the materials inventory, including any resulting transactions.
   - Estimate the potential reduction in transportation costs.
   - Do not forget all secondary costs of the reuse approach (specific support team, insurance, product testing, storage, ...)
   - If elements are reused by the same building owner (same location or not), consider mapping the savings on new products as an example of a cost-benefit analysis or part thereof
   - Assess all indicators defined at the beginning of the approach. Embodied CO_2, waste reduction, number of reused elements, reduction of new products/resources for other projects...
   - Use common LCA tools, self-made tools, tools from marketplaces (ex Cycle-UP), **DDC** tools.
   - Use RBIM tables to estimate the ultimate impacts of material reuse, and define which products are reused and recycled (low-value and high-value).
   - Use the Digital Materials Database to estimate the ultimate impact and determine which products have been reused and recycled.
   - Use a tender procedure for the selected demolition companies that can help to collect all costs and benefits (see chapter 8 for the details of the tender)
2. Recalculate future costs and benefits at their present value.
3. Assigning the correct costs and benefits to the decision to be taken.
4. An assessment of the completeness and quality of costs and benefits.
5. Selecting a decision model.
   - Use cost-benefit analyses on the **DDC** platform and the GreenFlex economic assessment tool.
6. Making the decision.

7. 8. QUESTIONS AND ANSWERS

The following questions have been addressed in projects on this topic. Each question has an answer.

Question: The VAT on materials for renovation projects is higher than that for new construction projects.

Answer: The cost differential can be reduced by reusing existing structural elements to reduce construction time and materials. The Bartlett School of Architecture's major renovation resulted in overall cost savings.

Question: Since minimizing the impact and waste of materials may be a deviation from the norm for construction, there may be reduced availability of low carbon materials. Materials that may have a higher cost (especially when combined with design for disassembly) and longer program implications.

Answer: By working with manufacturers and contractors earlier, it becomes easier to understand the availability and opportunities for low impact and wasteful materials that do not contribute to the cost and program. Also, alternative options are often not explored because tenders are discussed too late and the lack of time causes certain matching options to be lost and therefore revenues to be lost. Early involvement was key to the success of The Forge and The Entopia Building projects. The Enterprise Center was an experimental project to evaluate low impact materials, but the final price of the materials was not significantly different from previous alternatives.

7. 9. COMMENTS

There are no comments available yet.

7. 10. REFERENCES

Scientific references

Every choice in a cost-benefit analysis is based on an analysis of the opportunity costs (i.e., a (small) cost-benefit analysis). This is in line with the foundations of economics, which states that value can be attributed only to those things that are scarce and have alternative uses considering people's needs and behaviour (Robbins 1962). Lionel Robbins states:

"The economist studies the disposal of scarce resources. He is interested in the way in which different degrees of scarcity of different goods give rise to different valuation ratios between them, and he is interested in the way in which changes in ends or changes in means—on the demand side or on the supply side—affect these ratios. Economics is the science which studies human behaviour as a relation between ends and scarce means having alternative uses."

Materials in or for buildings are applicable in many ways and are scarce. That is why choices and (alternative) costs are always linked. Where no choice can be made about alternative use, such as with toxic substances or materials, a material also has no value. Nobel Prize winner James Buchanan quotes Frank H. Knight about the principle surrounding these types of costs:

" The idea of opportunity cost is central. The cost of any alternative (simple or complex) chosen is the alternative that must be given up; where there is no alternative to a given experience, no choice, there is no economic problem, and cost has no meaning. Economic cost, then, consists in forgoing some 'other' use of a given resource or resource capacity to secure the benefit of the use for which it is intended. The only general theory of cost that can be maintained will be that of opportunity cost."

Lionel Robbins, An Essay on the Nature and Significance of Economic Science, London 1962

J.M. Buchanan, Cost and Choice, Chicago, 1969

References within projects

1. Below are several examples of financial results from projects cited by the UK Green Council in its report "Insights on how circular economy principles can impact carbon and value."

Reuse of the substructure and superstructure of a building

1. **Triton Square:** Total project had a saving of 15-18.5% compared to new construction, partly due to the reuse of substructure and superstructure and materials.
2. **The Entopia Building:** Estimated to increase project costs by 4-8% over a standard Part L retrofit, but this was an experimental pilot project to maximise carbon reduction.
3. **Timber Square:** By retaining the building, there was a higher-than-normal floor plate value.

Facade reuse

1. **Triton Square:** £2m saving (10-20% cheaper than new façade) partly due to time savings.
2. **The Burrell Collection:** £100-500k saving by retaining aluminium facade.
3. **80 Charlotte Street:** Reuse of existing brick facade; some additional testing and modelling costs compared to purchasing a new facade project remained within budget and on time.

Material and product reuse, e.g., glass frames, brick, steel

1. Preliminary work by Cleveland Steel & Tubes and the UKGBC CE Forum suggests a 30-40% profit opportunity per tonne at current market prices for reused or reclaimed steel compared to virgin steel (32-44% saving), assuming the steel is in a client owned building; buying reused stock off the shelf is slightly more expensive but still provides a saving of 10-20%.
2. **JLL Office Fit-out:** Savings of over £40,000 achieved by giving the furniture package a second life compared to equivalent modern furniture.
3. **Cambridge Avenue:** Reusing the lift saved £5,000, and reusing materials provides a 25% cost saving in materials and products, but due to the complexity of the project this did not result in an overall cost saving compared to new build.

Higher rental values to demonstrate to tenants the improved usability of the space.

1. **Triton Square:** a significantly faster lease time than expected for a property of its type, although this cannot be attributed solely to the use of circular principles.
2. **Canal Reach:** The design allows for great flexibility in how many tenants can occupy the building due to the large floor plate. The building can be used as one building, split into two buildings or have up to 8 tenants per floor.

Flexibility can create mixed-use buildings with greater value.

1. **The Forge:** Floor-to-ceiling height and reversible components allow for future changes in use.
2. **80 Charlotte Street:** Steel base structure and pre-cast decking allow for future use.
3. **The Bartlett School of Architecture:** Common areas are designed to be flexible with some walls that can rotate or are lightweight, allowing for easier future layout configurations.

Income from resale of second-hand materials (for example steel from a portal frame)

1. **Building as a material bank approach:** material prices are increasing, future owners have stored value in the building components (value in the building itself, not just the land).

Future repair/maintenance/replacement cycle costs lower compared to business-as-usual.

1. This can save costs for the developer/client of the building if he wants to retain ownership of the building, or the future owner/user if he has some direct control over the usage phase of a building.
2. Applying passive design strategies can provide resilience as well as tailor systems to cope with future climate scenarios.

Lower future set-up costs as products and materials can be reorganised for different purposes.

1. Designing with flexibility in mind can ensure that materials and products are suitable for future use or reused by users in other buildings.

Where an external or internal carbon price is used, cost savings can be recognised by minimising impact and waste.

1. **Magnitude 314:** Lower compensation costs to meet UKGBC net zero construction framework.
2. **Holbein Gardens:** The incorporation of circular principles is expected to reduce the cost of carbon offsetting once completed.

Designing for waste is closely linked to designing for optimization, as minimalist designs lend themselves to greater flexibility and adaptability in the future. This reduces initial construction costs while providing a marketing opportunity for increased space utilization.

1. **Canal Reach:** Waste designed to have a visible structure, reducing the need for short life in leased areas; this had minimal/no impact on costs.

2. The Croix Luzet project near Lyon

- Demolition of a 100-unit building along the highway (Croix Luzet):
- **Inventory of materials:** 2600 m² solid oak parquet flooring, cast iron radiators, doors, cellar, roof railings, crinoline ladders, concrete
- After research, removal is estimated to be more expensive than reuse
- 3500 tons of broken concrete to redo the concrete, which is to say 50%. The rest to be supplemented or lost due to a lack of coordination in the chain upstream.
- Financial balance of + €50k on a total budget of €1.5 million
- Rehabilitation of student, elderly, and ESS housing in Villeurbanne (IUFM):
- Setting up in situ reuse (tiles, terrazzo, windows) and ex situ (metal walkways that become corridors, for example)

Croix Luzet teaches that financial results with sustainable demolition increase through:

- Putting reuse companies at the heart of the design and working with outcome objectives rather than available resources and capacities
- Encourage experimentation and pursue changes in traditional ways of working
- To enable the product to be reused at a lower cost by developing reprocessing and repair centres, for example for sanding and varnishing parquet floors, sanding radiators that have been varnished afterwards, stripped toilets, etc.
- Put the residents at the centre of the design or rehabilitation of their living environment. In this way, they get used to a new destination for, for example, their own furniture, and they start reusing part of the waste from the project.

8. PREPARATION FOR DEMOLITION

The result of the work for the preparation of the demolition of a building is an operational plan with activities that yield an agreed value of materials for the client.

The following process activities are part of the preparation of demolition activities:

- Recording the objectives of the demolition between the client (owner of the building) and the contractor (demolition company).
- Creating an operational demolition plan aimed at optimizing value for the customer.
- Setting up the work area, conducting risk analyses and providing the necessary capacities, machines, resources, and tools to conduct the demolition process.
- Define a scenario to follow to allow flexibility.
- Recognize with all stakeholders these aspects: timing, storage, costs, elements to be deconstructed and by whom and for what, destination of deconstructed elements.

8. 1. INTRODUCTION

This chapter describes the various preparations that must be conducted by a demolition or dismantling company if the execution of the demolition is to lead to a positive result for all stakeholders in a project. This means the delivery of those reusable materials that the owner of the real estate object wishes to obtain based on the registration of these materials in the digital materials database and the added value. In doing so, we assume the decision to demolish a building in a sustainable manner and to use the materials from the building in an alternative manner. This means selling them to a third party or reusing them yourself for a new building or the renovation of an existing building.

The data regarding the value of materials from a building determines which services are required from a demolition company in a circular demolition process. The material inventory quantitatively shapes the specifications. In other words, which materials must be removed from the building and how. The property owner also indicates the value of materials that the demolition company must deliver after its service, so that waste and loss of value of materials is prevented as much as possible. The timely material inventory also provides the space in time to organize the work in the best possible way, including finding buyers of the materials at the highest possible value.

For each project or pilot, it is important to design the specifications for the assignment to the demolition company in such a way that it is clearly indicated how the demolition contractor must handle the materials and how he must deliver the materials or bring them to the desired location for the materials. This can be a depot for low-value processing, or a depot of the property owner or the party that has already purchased these materials, or a processor for high-value processing (upcycling) considering the wishes of new users.

Registrations of a demolition company, a distinction must always be made in circular demolition between services and the value of the materials. In a classic method of demolition, everything is thrown together, which means that a lot of information about the materials is lost. Information that can give materials a lot of value, provided that the demolition work is conducted correctly. That is why a demolition company is ideally only asked about their services and to separate these from the proceeds of the materials and the costs associated with storing or processing materials.

In this way, an important insight is obtained into the cost-benefit analysis of each material for certain parts of the building, as well as the different costs of services related to the *"harvesting"* of each material. It also becomes visible to see which costs can be avoided in the future if parts of a building can be dismantled due to the choices made when constructing the building.

This chapter provides a step-by-step overview of the various activities, as well as the risks and necessary quality associated with the activities.

8. 2. INPUT

The demolition preparation has the following input variables:

1. The decision to demolish a building sustainably (Chapter 7)
2. The inventory and registration of the materials in the digital materials database (chapter 3)
3. The RBIM results regarding deconstruction steps, type and number of connections and their locations as part of tender documentation.
4. The availability of the 3D reversibility data and 3D viewer in the project documentation.
5. A summary of the degree of removability of the materials in the building (chapter 3). Use these results with the following information:
    a. The number of disassembly operations per product,
    b. Number of disassembly steps,
    c. The number of physical relationships per product/material
    d. Type and number of direct and indirect connections made during assembly and after assembly of the products to develop disassembly strategy
6. The social value of the materials in the building (Chapter 5)
7. Knowledge of these materials and value among employees
8. The available people, machines, resources, tools, and methods

In some cases, the following inputs are ideal, but not mandatory, when preparing for the demolition process:

- Disassembly tests allow us to identify the best disassembly method, so that the integrity of the product can be maintained. Try to observe the disassembly potential during a visit, or the later visit that is organized after the products have become available.
- Organize a specific visit with the demolition company. They can take an expert look and give advice.
- For true deconstruction of previous tests, focus on products that do not require heavy machinery (unless such machinery is already present).
- Drawing up a contract for the disassembly tests.
- The time for disassembly testing must be provided in the project schedule.
- If residual performance is not known and is critical (or required by users or a control agency), provide the required verification tests. Consult existing guides (for example French FBE guides on a range of products, which describe the verification protocols), consult product standards (national and/or European) describing the tests required for new products, speak to the control agency about the characteristics of the required tests and the tests needed.
- Minimize the number of tests (= costs) and take estimated performance into account where possible.
- Estimate the costs of contacting experienced local laboratories, manufacturers, or actors.
- Sometimes evaluates at universities are accessible. This saves on costs.
- Perform testing on representative samples.
- In all cases, think about insurance issues. Validate with the design team, with the inspection agency, with the insurance, that all necessary necessities are available.

8. 3. PRODUCTS AND SERVICES

In preparing for demolition, the work must be organized in such a way that the materials are delivered, as desired by the client, at the value for this client. This is based on the analysis of the available materials in a building, the degree of removability of these materials and the value of these materials.

This means that the services to be provided by a demolition contractor are aimed at delivering those materials of a certain value and that he is in fact also liable for this. In the contract between the client and the demolition contractor, the delivery of these values must be central, whereby points of attention such as damage, risks, force **majeure**, and all associated elements that are necessary to guarantee the value for the client are important elements. Such an agreement is therefore an important product. A difficult product when it is discussed for the first time.

A second important activity for the sustainable removal of materials concerns the preparation of people, machines, tools, and other resources to be deployed during the demolition of a building. A preparation that focuses on that combination of deployment of resources, that damages and other forms of loss of value can be prevented in different construction forms of a building. And where the value of the customer is central.

Derived from this preparation of activities, activities are then discussed that are operational in nature, such as setting up the work area, the ongoing risk analyses with regard to dangerous situations for people and machines, the use of electrical and motor aids, the logistical flows with regard to materials in the workplace and the removal of these materials.

It was previously indicated in chapter 7 that the timely organization of the buyers of the materials and thus also the removal of the materials is an important yield-promoting activity. Therefore, also start by organizing the end of the trajectory well, because it is precisely in this link that the most added value is created in a social cost-benefit analysis about Circular Demolition.

8. 4. METHODS, TECHNIQUES, TEMPLATES AND INSTRUMENTS

Sustainable demolition focuses on value creation for the customer in the form of maximally reusable valuable materials. In this, techniques from the world of optimising production processes, such as the Lean philosophy, as originally developed by Toyota, can play an important role. Using the Lean philosophy in demolition is new but can be an important quality instrument for the entire sector for the provision of services.

If a tender is used to organize the cooperation between the property owner and the demolition company, the templates for this tender should focus on:

- The information about the building in the tender documents
- Mentioning all elements related to the reuse approach in the tender: technical inventories, reuse objectives.
- The provision of a catalogue/inventory of the possible elements for reuse.
- The organization of visits to locations.
- Surveying experienced building owners to share approved tender documents and contracts.
- The selection of experienced and strong references on the reuse approach.
- The selection of the company with the highest added value. Not with the lowest costs.
- Collaborating with local teams. They know the local network better; construction sites come and go will be more present during the project.
- Choosing experienced companies with strong references in the field of deconstruction and reuse.
- The question of the use of methodology, initial ideas, etc. Information specific to the project.
- The demand for information from companies on methods of deconstructing, storing, and transporting key products.
- Provide drawings of the elements that would be reused, provide a catalogue of all the elements integrated into the reuse approach.
- Organizing visits.
- Requiring companies to provide proof of insurance for the implementation of reuse solutions.

- Being clear about the objectives (deconstruction actions, requirements for the quality of products after deconstruction, % damage, timing, responsibilities for storage and transportation, etc.).
- The purchasers of the materials that are released.

8. 5. RESULTS

The result of the work for the preparation of the demolition of a building is an operational plan with activities that yield an agreed value of materials for the client. Not primarily a clean site, but a combination of labor, resources and working methods, which yields both a clean site and an optimal value in alternatively applicable materials. Work for which the demolition company is compensated in terms of its services, and no longer in the form of a combination of compensation for services and its own proceeds from materials. After all, the latter now belongs to the owner of the building.

8. 6. QUALITY FACTORS

The quality factors that are addressed in this part of the work are very similar to the quality factors that are also addressed in production and/or logistics companies in terms of their operational processes. It is important that a certain quality standard or philosophy is used. An example of the first is working with ISO standards. An example of the second, which goes much further than a standard, such as ISO alone, is the Lean philosophy.

8. 7. PROCESS ACTIVITIES

The following process activities participate in the preparation of the various demolition activities:

1. Recording the objectives of the demolition between the client (owner of the building) and the contractor (demolition company).
2. Creating an operational demolition plan aimed at optimizing value for the customer, given the boundary conditions as agreed in the contract award.
3. Setting up the work area, conducting risk analyses and providing the necessary capacities, machines, resources, and tools to conduct the demolition process.
4. Define a scenario to follow to allow flexibility.
5. Recognize with all stakeholders these aspects: timing, storage, costs, elements to be deconstructed and by whom and for what, destination of deconstructed elements.
6. Use the **DDC** platform and tools to identify the potential of the existing building and potential scenarios.
7. Use the digital reversibility of a building to define design requirements for the design team and the required circularity profile of the building, as well as deconstruction and reuse requirements for the contractor.

8. 8. QUESTIONS AND ANSWERS

The following questions have been addressed in projects on this topic. An answer has been provided for each question.

Question: Do you request different quotes from the demolition company for a classic demolition method and a circular demolition method? If so, how do these quotes differ?

Respondent 1: Normally not. Prior to the tenders, we signal the willingness to apply a circular process. That is why we include this question in the tender documents, and the offer is drawn up based on these requirements.

Respondent 2: No. If circular demolition is requested, this is stated in detail in the tender document, and it is the only quote requested.

Respondent 3: Up to now: no. From now on, of course. We are thinking about how we can best provide this in our public procurement documents.

Respondent 4: Normally not.

Respondent 5: Yes, the demolition company must estimate the cost difference between a demolition and a deconstruction. It depends on the materials, sometimes it is the same protocol, and sometimes it is much more complicated to deliver the material without damage. So, the quote can be different between the two methods.

Question: Local authorities may impose requirements for the preservation of a building's heritage features, which may hinder improvements in energy or material efficiency.

Answer: Many local authorities have declared climate emergencies and/or set far reaching carbon reduction targets. These can be referenced alongside the potential carbon savings from replacing the heritage features of the building. Cambridge City Council's conservation team (Entopia Building) wanted to retain the appearance of the Georgian windows, which would limit natural light and operational energy efficiency improvements. By demonstrating how carbon savings would align with the council's evidence-based reduction targets, and how the windows could be changed whilst retaining the key heritage features of the building, a compromise was reached.

Question: Unknown building elements can increase program time and costs.

Answer: Ensure that time is allocated in the program to assess the condition of materials before the project begins. The availability of passports will make it easier to resolve these issues in the future.

8. 9. COMMENTS

There are no comments to add yet.

8. 10. REFERENCES

References within projects

The desire to supply the stones from Ettelbrück station as separate products for reuse means that there is no question a classic demolition process, but for a dismantling of the building. As desired by the building owner, a quotation was made in the project phase for a classic method of demolishing the building but later supplemented with quotations for a sustainable method of dismantling, as described in the tender documents. It concerns various materials with different values, whereby each material calls for its own cost-benefit analysis, whereby additional costs up front (inventory and analysis), the additional costs for dismantling (how high are these), are weighed against the additional revenues of scarce materials. For the continuation of the pilot, an interview is planned with the demolition/dismantling company about the various efforts in a traditional demolition process and the activities that are conducted in a sustainable demolition process, including the differences in costs/benefits and different working methods. The demolition company will work with *"gold (scarce stones)"* and what does this mean for them. And how to deal with materials that are becoming increasingly scarce, and the effect on their way of working now and in the future.

9. THE EXECUTION OF THE DEMOLITION AND THE SECURING OF THE VALUE OF THE MATERIALS.

The result of the demolition process is the "handing over" of the materials from a building to the owner of these materials, so that the materials can then also be used alternatively,

The following process activities are part of the execution of the demolition and the securing of the various materials and their value:

- Conducting the demolition work
- The design and support teams must strictly monitor the deconstruction work, collect the documents, take photos, manage the recovery of deconstructed elements by targeted actors, report deconstructed, sold, stored elements.
- Separating and removing the materials
- The ongoing evaluation to make improvements to prevent damage, loss, or waste in relation to customer value.

9. 1. INTRODUCTION

This chapter deals with the way in which the value of materials can be effectively secured during demolition work. It describes various methods, techniques and procedures that should ensure that waste of materials and damage to materials are prevented, so that the value of materials remains as high as possible. And the requirements of the owner of the real estate object, who is liable for the delivery of the materials with a certain value to a buyer of the reusable materials, can be met.

9. 2. INPUT

The operational demolition plan

1. Setting up the work area
2. The availability of risk analyses
3. The availability of capacity, machines, tools, and resources
4. Knowledge of materials and the value of materials among employees
5. Methods and craftsmanship for sustainable demolition.
6. The use of instruments from the quality framework used by the demolition company, for example from the Lean philosophy.

The broad understanding of the demolition company and its employees of the concept of *"value for the customer"*, the prevention of "damage and waste" and awareness of the consequences of *"liability"*.

9. 3. PRODUCTS AND SERVICES

The demolition company provides the following services in the operational demolition process based on the operational demolition plan:

1. Removing, stripping and/or dismantling stairs, frames, roof structures, ceilings, floor finishes, wall finishes, roof finishes, installations, stone walls, partition walls and wooden beams.
2. The removal or demolition of the structures of a building.
3. Separating the different materials at the source
4. The removal of the various materials to the depots for these materials or the reuser of the materials.

9. 4. METHODS, TECHNIQUES, TEMPLATES AND INSTRUMENTS

The techniques, templates, and instruments available for the execution of the demolition belong to the domain of the demolition companies themselves. This concerns methods, tools, resources, machines, and trained people. And instruments that are aimed at avoiding damage, loss, and waste in the operational process, so that the value for the customer of the reusable materials is secured. In this manual we will only speak in general terms about these techniques, templates, and instruments. For the time being we leave the specific descriptions to the demolition companies themselves.

9. 5. RESULTS

The result of the demolition process is the *"handing over"* of the materials from a building to the owner of these materials, so that the materials can then also be used alternatively, in accordance with the agreed agreement.

9. 6. QUALITY FACTORS

The quality factors in the process of sustainable demolition are influenced by the standard that imposes the *"value for the customer of the reusable materials."* Derived from this standard for quality, many common quality factors will still be addressed at a demolition company, such as those relating to safety and working conditions. However, the focus on the various quality factors can change if the focus is not on a clean site, but on the implementation of the optimal social value for the customer in general. Depending on the development, vision and mission of a demolition company, the quality thinking will undergo small or large changes, which will lead step by step to a process of continuous development and improvement based on the development of employee competencies, evaluation of business processes, cases, **kaizen** workshops etc.

In this manual we will for the time being only follow the general development here. The detailed application of quality is left to the demolition companies themselves.

9. 7. PROCESS ACTIVITIES

1. The following process activities participate in the execution of the demolition and the securing of the various materials and their value:
2. Conducting the demolition work
3. The design and support teams must strictly monitor the deconstruction work, collect the documents, take photos, manage the recovery of deconstructed elements by targeted actors, report deconstructed, sold, stored elements.
4. Separating and removing the materials
5. The ongoing evaluation to make improvements to prevent damage, loss, or waste in relation to customer value.

9. 8. QUESTIONS AND ANSWERS

The following questions have been addressed in projects on this topic. Each question has an answer.

Question: Visual appearance of recycled materials can reduce the rental potential of a building.

Answer: Find examples of reused assets or materials to show clients and agents, and ensure they understand the marketing potential of low carbon or circular properties. In the Entopia building, the client was initially hesitant about the reused raised access floor as a visible finish, but after seeing a similar example, they supported the installation of the floor.

9. 9. COMMENTS

The following comments can be added to this chapter.

Comment 1: If materials are not directly traded, the shadow price of the primary materials can be used as an alternative to describe the value of the materials. Given the pricing on local markets, in this case averages for multiple markets will have to be drawn up to obtain the correct data.

9. 10. REFERENCES

References within projects

The stones in the Ettelbrück station have already been donated to the INPA (Institut National du Patrimoine et de l'Architecture). The INPA wants to reuse the special stones to rebuild the same station in another location. The stones come from a quarry that has been closed for a long time, which makes the stones very scarce and therefore of great historical value. Including the saving in CO_2 (including value) by reusing these stones. For the continuation of the pilot, an interview is planned with the future owner of the stones, so that we can get an idea of the alternative value of the stones. We can also gain insight into the costs of repairing the reusable materials, and the costs of storage and wear.

10.

SECURING THE MATERIALS IN A DEPOT

ith a depot or stock, a condition is set up to bridge the supply and demand of reusable materials in a physical sense. The administrative and digital side of the depot enables us to organize the matching between supply and demand, and to provide an overview of all available materials, to prevent damage, loss, and waste in this way.

When securing the various materials in a depot, the following process activities are involved:

- The delivery of the materials to the depot (inbound)
- The method of storage and inventory management of the materials
- The delivery of materials from the depot based on order processing (outbound)
- The digital administration of all inbound and outbound processes, partly based on the ownership rights of the materials from the digital materials database.
- The continuous improvement of the various processes based on the quality standards and/or philosophy behind them.

10. 1. INTRODUCTION

To physically reuse materials, the detached and removed materials from a real estate object must be stored in a depot for the period that they will not be used or await reuse.

This chapter describes the various aspects of securing materials in a depot, including reducing the costs that can be associated with keeping materials in a depot. After all, the fastest way to reuse materials from a real estate object is directly from a building to a new building. However, this does not always have to be the best way, because in addition to costs, benefits can also be linked to securing materials in a depot, if certain economies of scale and scope can be achieved that cannot be achieved with a single reusable material. This also applies if materials need to undergo processing to meet the demand of users again. Temporary storage is also necessary in such a case of upcycling.

In this chapter we assume a physical depot of materials, which is comparable to a wholesaler with a storage area. However, this certainly does not always have to be the case, because with a digital materials database linked to the blockchain registration, the building itself can also be seen as a depot, or urban mine.

10. 2. INPUT

The materials resulting from the demolition process.

1. Depots to store the materials.
2. Discount rates for calculating the present value of materials over time.

10. 3. PRODUCTS AND SERVICES

The central product in this chapter is not only the possibility to store materials in a way that retains their value, but also to be able to deliver them in such a way that they can be reused at the highest possible value. After all, storing materials for a longer period is a loss of value of these materials, because the materials cannot be used for productive functions in a building. In this respect, we are ignoring the speculative value of material stocks, because of price changes.

The function of a stock is to fill in various forms of questions from new users. To be able to combine these with each other with new products, or to guarantee direct delivery of a product, so that one does not have to wait until a building yields new materials from a demolition process.

The extent to which demanders and suppliers can be combined more quickly without loss of time is therefore the central product in this chapter. Derived from this product is then the reduction of the problem of damage, loss or waste that is associated with stock formation, in accordance with the business operations of every logistics company or wholesaler. The longer the time between a match of supply and demand, the higher these costs will be, including loss through use, which can be made visible by means of the discount percentage of loss of value of materials in depots.

10. 4. METHODS, TECHNIQUES, TEMPLATES AND INSTRUMENTS

A material depot has both a physical side, in accordance with the storage location at each wholesaler or distribution centre, and a digital side in the form of a stock registration system. Such a system can be used for the administrative handling of inbound and outbound processes of the materials in a depot, as well as providing an overview of the materials that are available for the sale. The stock registration system can be a specialisation of the digital materials database or be linked to this database via an API.

10. 5. RESULTS

With a depot or stock, a condition is set up to bridge the supply and demand of reusable materials in a physical sense. The administrative and digital side of the depot enables us to organize the matching between supply and demand, and to provide an overview of all available materials, to prevent damage, loss, and waste in this way. These results can be used again in the next step of the sustainable demolition process, namely the trading of reusable materials based on their registered property rights.

10. 6. QUALITY FACTORS

The quality factors that are important in the stock formation and stock management of reusable materials are the same as those for the quality standards of wholesalers and/or distribution **centers**. Here too, for example, the application of Lean philosophy can be useful.

10. 7. PROCESS ACTIVITIES

When securing the various materials in a depot, the following process activities are involved:

1. The delivery of the materials to the depot (inbound)
2. The method of storage and inventory management of the materials
3. The delivery of materials from the depot based on order processing (outbound)
4. The digital administration of all inbound and outbound processes, partly based on the ownership rights of the materials from the digital materials database.
5. The continuous improvement of the various processes based on the quality standards and/or philosophy behind them.

10. 8. QUESTIONS AND ANSWERS

The following questions have been addressed in projects on this topic. Each question has an answer:

Question: Do you have a temporary depot to store materials for reuse? Or is such a depot set up at external parties, who also takes care of the processing of the materials into reusable materials?

Respondent 1: Not yet. The processing of the materials guides the deconstructor, based on the requirements of the consultant.

Respondent 2: The materials to be sold or reused are stored on the site itself, in a part of the building that is preserved. For other projects this may be different. This storage issue will therefore be considered/answered in line with the project.

Respondent 3: Not yet for the building, but we have a depot for materials from infrastructure projects.

Respondent 4: Not us, but we have the goal of creating a depot in each region of France to store material. We are currently looking for internal sites.

Question: It is difficult and expensive to store and pass on used products for reuse.

Answer: Work with material exchange platforms, such as Globechain and **Collecteco**. Also consider donating materials for social value creation.

10. 9. COMMENTS

The following comments can be added to this chapter.

There are no comments yet that can be linked to this chapter.

10. 10. REFERENCES

References within projects

Storing materials at the French Railways – the Villeneuve St. George project

Storage is provided for materials for which **in-situ** reuse has been confirmed or for which buyers have been identified for ex-situ reuse (according to the Interreg/VSG construction planning coordination). The construction company provides storage (organisation, fencing, security, cleaning etc.).

1. Ex-situ storage of materials:
   a. If each potential ex-situ reuse material is sold, we calculate between 200 and 250 m² of storage space.
   b. In the tender document, the SNCF proposes two options for 9 months of 250m² storage for ex-situ reuse:
   c. A storage area designated by the SNCF around the construction site: a city parking lot rented by the city. Some restrictions: the parking lot is in a flood zone and is accessible from a tunnel, avoiding the movement of oversized materials (e.g., structural components) from the construction site to the parking lot. This requires more restrictive dismantling and new packaging considerations.
   d. A second zone to be identified by the construction company with an estimated cost of 18,000 Euros. Several construction companies have estimated the cost of this zone at 10,000 to 100,000.
2. In-situ material storage:

If potential in-situ is confirmed for the materials, we calculate approximately 90m² of storage space.

- **Glass:** 16m² storage space
- **Mineral/concrete cladding (canopy):** 27m² storage
- **Stone facade (canopy):** 7m² storage space
- **Ceiling:** 15m² storage room
- **Ceiling lamps LED 60x60:** 2m² storage space
- **Kitchen appliances:** 20m² storage room
- **Internal doors:** 2m² storage space

11.

PROCESSING

The results of the processing process are the availability of secondary materials for the realization, renovation, and maintenance of buildings

11. 1. INTRODUCTION

The desired integral cycle of circular use of materials currently only exists for a few materials, such as metals. For the other materials, there is no cycle, because after using the materials in a building, most of the materials are dumped, burned, or reused at a low value after demolition (no disassembly). For these materials, it is economically cheaper to buy new materials than to let existing materials undergo the actions of the cycle. However, for more and more materials, this balance is starting to shift, driven by price increases for new materials, geopolitical interests to obtain raw materials from the Urban Mines of Europe, instead from countries outside the European Union, as well as the pricing of the social costs related to the destruction of existing materials. This is done through liability and CO_2 prices to produce alternative new materials (ETS rights).

Examples of waste processors of building materials show that waste is increasingly becoming a raw material, because after sorting and cleaning the materials, new raw materials are created that are competitive with primary raw materials. The same goes for products. Not because these secondary raw materials have now really become cheaper, but because the costs of primary raw materials are rising explosively. This creates a business model for the cycle of secondary materials, in which inventories of the costs and benefits of actions in this cycle model are of great importance in order to give as many stakeholders as possible in buildings an integral insight into their own derived revenue model, which often includes part of the entire cycle. This is in comparison with a classic method of building and demolition, in which the disappearance of materials is an issue.

A cycle that not only has the physical flows of materials as a basis, but also the underlying legal and market structures (market masters) to further organize long-term contracts with materials in the chain. Precisely because in the cycle multiple stakeholders are continuously connected to each other in an enforceable way. In the classical way this legal infrastructure is absent, which results in waste being the norm, because the cycle can never be closed due to the loose cohesion between stakeholders.

Relatively high costs in a traditional method of demolition are caused by the transport costs to deposit the materials at a suitable waste location or at a location for low-grade processing of materials, as well as the processing of these materials. These costs must be mapped out for each project with low-grade material processing. It is expected that these costs will also increase, because increasingly higher demand is being made for the processing of these materials. Also, with low-grade reuse. It is true that these costs often have a local characteristic. Because higher costs of *"depositing"* reduce the relative costs of circular demolition, it is important that these costs, including the associated social costs, are monitored over time for strategic decision-making by each owner.

This also applies to the processing costs of high-quality material into new materials, or the direct reuse of material products. These costs, ranging from transport, cleaning, storage, and processing to new products, will also have to be made transparent, so that they can be included in strategic decision-making processes about the handling of materials from buildings. Local processing costs per material will primarily be the norm here but can be followed on a central platform if various (pilot) partners also supply the data for this.

Through (hopefully) innovations, processing costs of low-grade and high-grade processing per material can be made increasingly clear. This requires investment in collecting and presenting data, which can also be supplemented with examples that are used in other parts of the circular demolition process.

In Belgium, for example, the Vlamera 8 law has come into effect. This will apply from January 2023. According to this law, recyclable waste may no longer be incinerated but only processed. The aim is for clean processing materials, because pollution can occur during the processing of concrete, for example, or through pollution in the concrete itself. Biobased fibres and synthetic fibres may be used in concrete. Steel fibres are not, because they will erode. This can cause chemical pollution or structural weakening.

In general, it can be said that little research has been done into the reuse of materials by waste processors or other parties in the chain. An example is concrete. It is known that concrete contains chemical residues, that contamination can cause safety risks and that structural weakening can also occur. In fact, there is no legislation for the reuse of concrete. Only NEN 2767 comes close.

Renewi indicates that a major transition is taking place in container processing. For example, materials are becoming increasingly valuable and the demand for reuse is growing. Material passports can be very useful for waste processing. Little to nothing is usually known about waste that is currently coming in.

Waste processing is becoming increasingly sophisticated. Large installations are needed to process mixed flows. A new processing plant is being built in Heerle (Brabant). By setting up new installations, many materials and therefore also CO_2 are saved. Renewi indicates that this is approximately 23,000 tons of CO_2 per year. This has a value of 1,472,000.- according to the current prices of CO_2 rights.

Renewi indicates that waste processing is becoming increasingly large-scale, also because good waste processing produces new materials with high added value. Given the rising prices of primary and therefore also of secondary materials, the delivery of materials to the processing plants is now also paid for.

11. 2. INPUT

The following inputs are used as input for the processing of materials.

1. Materials from the depots
2. Materials directly from a building
3. Material passports of the materials
4. The degree of *"beauty"* of the materials.
5. The transport of the materials to the processor.
6. Processing installations for materials as waste
7. Tools for refurbishing, repairing, or restoring materials.

11. 3. PRODUCTS AND SERVICES

The central service in the processing of waste from building materials is the conversion of materials of lower quality into materials of that quality, so that these materials can be used directly for a building, or are processed into semi-finished products, with which the industry can make new products for construction. All this primarily without loss of material, leading to new values for building functions and with minimization of the various environmental costs. The services are provided in processing plants, where large quantities of construction waste are sorted based on various aspects, such as size, type, beauty, etc., and are processed into clean granulate of this material. Or it concerns *"refurbishment hubs"* where products for construction are repaired, or for example made to measure. Here too, it can concern a range of products and materials, but the most important thing is that no physical piece of material is lost.

11. 4. METHODS, TECHNIQUES, TEMPLATES, AND INSTRUMENTS

The methods, techniques and instruments used in processing plants belong specifically to this company. It would go too far in this Manual to go into this in detail.

11. 5. RESULTS

The results of the processing process are the availability of secondary materials for the realization, renovation, and maintenance of buildings. And indeed, at a social value that is comparable to the price or value of primary materials. The quality of the secondary materials is known, the connection to the demand of new users, as well as the availability of these materials.

11. 6. QUALITY FACTORS

Quality plays a central role in the reuse of materials in buildings. The processing or restoration process of materials therefore aims to restore the functional and relational quality of the materials, in such a way that they meet the demand of the new owner of the materials and do not detract from the safety and functionality of the materials.

11. 7. PROCESS ACTIVITIES

The process activities used in processing plants belong specifically to this company. It is beyond the scope of this Manual to go into this in detail.

11. 8. QUESTIONS AND ANSWERS

Question: Costs associated with reprocessing or cleaning materials (e.g., reclaimed stone) and uncertainty that materials will meet warranties and performance specifications.

Answer: When specifying reused materials, only purchase reused items that have a warranty. These costs and risks are expected to decrease as the industry becomes better equipped to support a circular construction sector (e.g., development of circular infrastructure, increasing awareness of repair processes, etc.).

11. 9. COMMENTS

Further analysis in material processing – guidelines for the manual

Comment 1: Delivering clean materials to a processor increases the costs of the demolition company or the dismantling company but leads to higher quality materials when processed. And therefore, more revenue for the processor, or lower costs for dumping or incineration. The processor will share this higher gross margin with the demolition company for his or her preliminary work.

Comment 2: Making a 3D scan in the inventory process reduces the costs of the removability analysis for a building, because 3D data can be read directly into a BIM model for this analysis. This then reduces the total costs of the inventory, which makes the business case of the cycle more accurate in total.

Comment 3: Inventory of materials improves the transparency of the materials, especially about quantity (removability) and quality. Transparent quality increases the value of these materials (*"the Lemon problem"*), after which the costs of inventory could be paid from the sale of the materials.

The cycle of materials can be improved repeatedly with similar examples, whereby the manual aims to share and secure these examples, so that the various stakeholders know from each other why the action of one can also be profitable for them. So, if I make a 3D scan at the front of the cycle, how does that lead to cost savings for the purchaser of the processor, who then makes new raw materials or products of the right quality?

Or the other way around, if the processor is going to pay for the purchase of waste, this means a direct incentive for the storage of materials, as well as the demolition or dismantling company, to work very efficiently and effectively, because dumping and incineration costs are avoided, and they will be paid more for the delivery of *"raw secondary raw materials"*. In this way, the manual responds to the prevention of *"system failure,"* or insufficient coordination of actions of added value of subsequent chain partners, which negatively affects or even nullifies the business model for the next in the chain. The manual makes these costs, benefits, and associated actions transparent, so that parties in the cycle can make better agreements about quality, as well as compensation for their additional part in the chain.

The demolition or dismantling company then has an incentive to know exactly where valuable materials are present in a building, whether they can be removed efficiently and with little or no loss of value, etc. There will also be an incentive for the *"warehouse manager"* of the cycle to strongly reduce the costs of stocks and storage with a rapid delivery to the processor, who for example makes granulate from it, instead of weighing up storage costs against the costs of dumping or incineration. These latter costs of waste, including the social costs thereof, will then disappear, or at least be drastically reduced.

In this circular approach, we can then not only determine the additional costs and additional benefits of an extra step for the next link on the way to a closed loop for each link but also gain insight into the nature of a disruption. After all, as the processor's case shows, improvements in some links require investments. And some investments cannot always be paid directly from a company's liquidity. Or where there is a temporary unprofitable peak, as is the case with the marketplace for trading on the *"titles/tokens"* for materials.

These obstacles can emerge in the cases and should be mapped with the descriptions in the manual. They will then be placed on the *"fund list,"* to which government funds or investor resources can be linked.

Three lines/scenarios are provided for searching for information and sources of the manual:

1. Mapping the direct visible costs of all actions in the cycle (classic or circular) to be expressed in Euros per 1,000 kilos of glass, polymers, and concrete. Each cost description is given a paragraph in the manual with the appropriate component.
2. Mapping efficiency gains of investments and innovation in one part of the cycle inproving on the other parts of the cycle on ther way from classic to circular (interventions). For example, from inventory on demolition/disassembly, or from processing to the purchase of raw materials. Always expressed in Euros per 1000 kilos of glass, polymers, and concrete. Each intervention will be described in the relevant paragraph in the manual. A list will be made of types of interventions throughout the cycle, arranged according to link-to-link effect.
3. Mapping the effects of *"tipping points"*. That is, events that lead to closing the loop instead of disrupting it. For example: earning money from the delivery of waste, instead of paying for it. Or setting up a marketplace for trading rights to materials. Tipping points result in major behavioural changes of all stakeholders and subsequently cause major disruptions in the development of a market. Each *"tipping point"* belongs to a specific link in the loop, which is described in the manual.

11. 10. REFERENCES

There are no references yet for this chapter, other than those shown in the comments section.

12.

MARKETPLACES

The outcome of a marketplace is the successful transaction, expressed both in terms of transac tion volumes and the total value of transactions.

When trading reusable materials in a (digital) marketplace, the following process activities are involved:

- The physical setting up of the marketplace in the form of a digital application.
- The legal structure of the marketplace allows buyers and sellers to enter the digital marketplace.
- Publish information on marketplaces
- The legal shaping of transactions on the market in the form of agreements
- Organizing management and supervision of the market and the various transactions
- Applying a process of continuous improvement.

12. 1. INTRODUCTION

The central activities around the reuse of materials in buildings focus on the connection between the owners of these materials in a building and the stakeholders who can determine if and where these materials will be reused. A connection that under certain conditions can also lead to a transaction regarding these materials on a digital marketplace. In the project plan **Demo Blog** this is called *"the improved marketplace for architects"*. The central goal in which the Materials Database Cirdax plays an important supporting role, both as a data source for materials (the old version) and a tool for stakeholders to define their needs in the field of materials, including secondary materials.

An enriched marketplace for the continuous (re)use of materials has a two-way relationship between stakeholders, via the marketplace itself, as a starting point. It is therefore different from a one-sided marketplace or webshop where materials from buildings are offered to anonymous buyers. The framework for an enriched marketplace for materials from buildings, as described in the work on the DBL Cirdax, consists of four separate elements that together form a marketplace framework for secondary materials:

1. Transparent delivery of building materials by property owners based on a Materials Database, such as Cirdax or Concular.
2. The demand from stakeholders in the built environment for secondary materials, in particular the demand from architects and construction companies. (Stakeholder suite)
3. The manner and conditions under which transactions involving secondary materials can be conducted, including the role of blockchain in ensuring ownership of materials (see also Chapter 4)
4. Establishing a (regional) economic order within which transactions with secondary materials can be organised in a sustainable manner (see section 9 of this chapter).

All four elements are strongly connected, because without the supply of secondary materials there is no demand for these materials. If the quality of the secondary materials is insufficient or unknown, these materials will not be used anyway. The stakeholder suite therefore offers stakeholders such as architects and construction companies the opportunity to define their demand for secondary materials, with the supply of potentially reusable materials being provided by Cirdax itself. In this way, stakeholders can work on aligning supply and demand.

Assessment of the circularity of multiple cycles

The most characteristic challenge of circularity concerns solving the problem of asymmetric information between sellers and buyers of building materials. That is, how buyers and sellers in a marketplace can enter a transaction with each other, even if this transaction with respect to a material is far in the future. The problem of asymmetric information is also called the Lemons problem, after Akerlof (1970).

The problem of asymmetric information when using a Digital Materials Database is also called the problem of multi-cycle circularity assessment. This can be translated as follows. The cycle of a material starts in the world of circularity with the inventory of the quantity and quality of the materials in a building (chapter 3). This assessment of the materials is recorded in systems such as Cirdax or Concular, which serves as a data management system for these materials. Transparency in information about these materials is the first step in the multi-cycle assessment and reduces the problem of information asymmetry on the supply side of materials.

The second test within the materials cycle concerns the mapping of the need for secondary materials by a future user, such as an architect or construction company. This user must consider various aspects concerning the quality of materials, such as legislation and regulations, quality, and suitability of the materials. He or she will assess the need for secondary materials based on the availability and quality of the secondary materials (second assessment). This assessment is supported by the Stakeholder Suite, which is explained further in this paragraph.

The match between demand (need) and supply creates a transaction, where the material is the object of the transaction. But a transaction itself is also part of specific forms of asymmetric information, which often arise when using the material after purchase. If a material does not meet expectations (the third assessment), the question of liability arises. This can also be organised based on the property rights that are linked to each material and are visible in the material passport of a material. Because this property right is created based on blockchain registration, it is always possible to find out who the previous owner was and who must take care of it. Compliance with the (private) contract that is linked to the delivery of the material. This third assessment completes the cycle of a material and its reuse.

Available materials can thus find a new owner by making these materials part of a transaction between a buyer and a seller of these materials. Buyers and sellers can efficiently manage these transactions in the marketplace. This can be a digital or physical marketplace. To function efficiently and effectively as a marketplace for reusable materials, the marketplace must meet a few requirements. These requirements can also ensure that the operation of this marketplace is so effective and efficient that the value of the various materials also increases. An effect that can last throughout the entire chain, as described in this manual.

In summary, the assessment of the multi-cycle circularity of a material consists of three parts: 1. Inventory, 2. requirements formation and 3. the (enforceable) transaction. Blockchain registrations provide the functionality to record ownership rights, enabling transactions on a digital marketplace. Furthermore, it ensures that buyers (architect and/or construction company) and sellers can make binding and enforceable agreements with each other, which also provides a legal basis for the stakeholder suite.

Cost-Benefit Analysis for Marketplaces

In the process prior to the sale of materials from a building, these materials are processed, the origin and quality of the materials are registered and verified, so that problems arising from asymmetric information (the *"lemons"* problem) do not arise. This means that in terms of costs, only those costs are incurred that are related to the process of sale or alternative internal use of the materials, and the possibility of converting the saved CO_2 emissions into tradable emission rights and the sale of these rights.

Since the social return of saved CO_2 cannot yet be converted into money, the financial return will be equal to the value of the materials on a (digital) marketplace, which is comparable to primary materials at the same quality, minus the sales commissions of the digital marketplace. In other words:

$$Mc = Mb + Mm - P$$

Whereby:

Mc: the proceeds from the sale of materials

Mb: the financial income from the sale of materials

Mm: the social return from the sale of materials

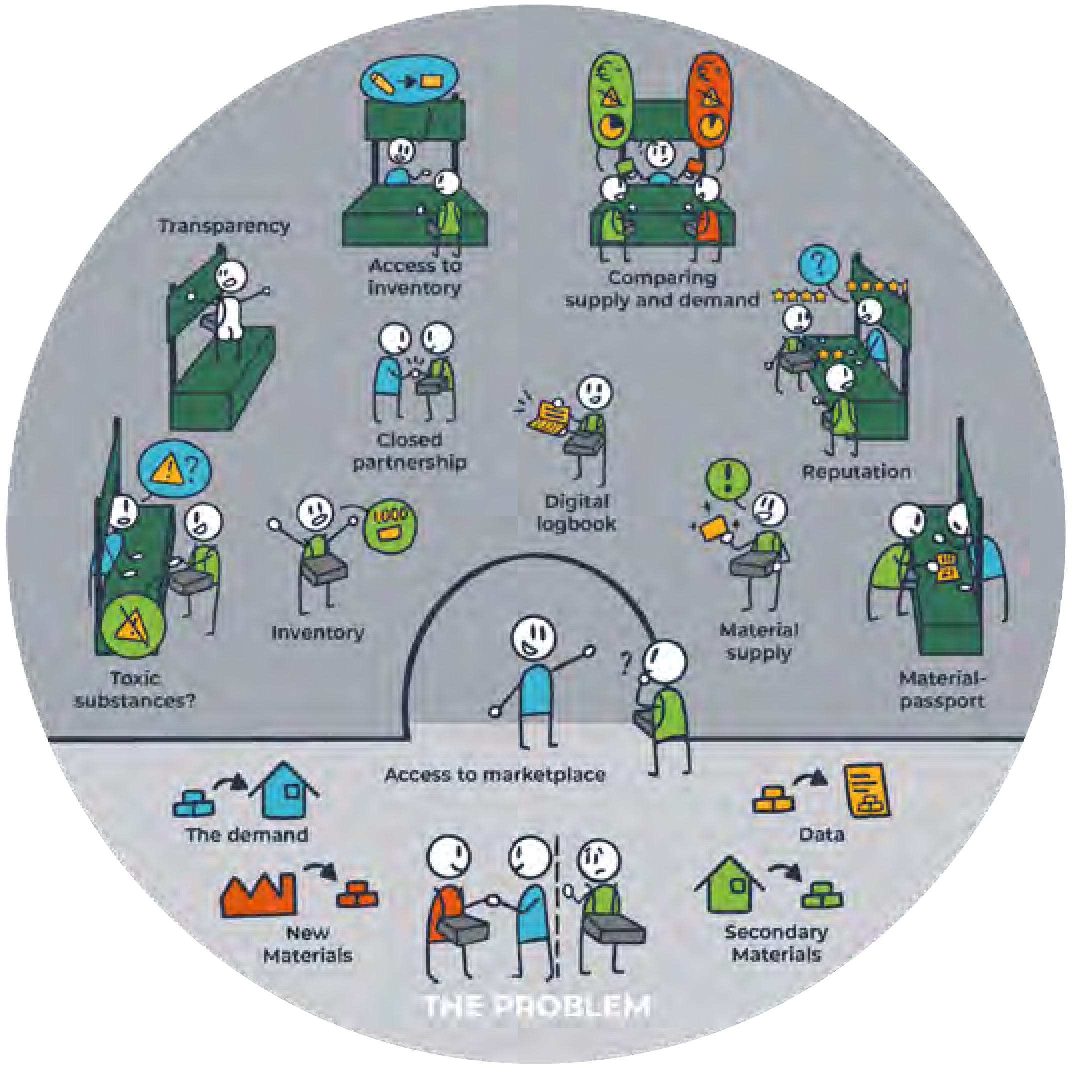
P: the commission on sales associated with the marketplace used for the sale.

To follow Mb, prices will have to be determined for all materials. If these materials are not traded directly, the shadow price of the primary materials can also be used for this. Given the pricing on local markets, averages for multiple markets will have to be drawn up in a cost-benefit analysis for the correct data.

To track Mm in money, the amount of CO_2 saved from a material must be known. Then this saving, as well as the size of the materials, can be multiplied by the CO_2/ton price of emission rights, which is traded on the EEX. This emission price is currently around 70 Euros per CO_2/ton (May 15, 2025).

The commission on the sale of materials assumes that there is a market for reusable materials. However, these are currently very local or non-existent. Normally, a commission on a transaction varies between 0.5% and 5% of the value of the material.

For a strategic analysis of the costs and benefits of circular demolition vs. classic demolition, the different sales prices of the most common materials in a certain environment need to be continuously monitored to correctly implement this strategy. This also applies to the shadow prices on saved CO_2, which can only actually be included in the cost-benefit analysis if the rights to the saved CO_2 are also tradable. At present, they can only be mentioned in technical and quantitative terms.



12. 2. INPUT

Available materials, including the ownership rights to these materials, as recorded in the blockchain registry linked to the digital materials database

1. Buyers
2. Sellers
3. Information about the materials in terms of quantity, quality, and availability.
4. Prices of the different materials.
5. Market accessibility in terms of conditions relating to market entry and exit.

12. 3. PRODUCTS AND SERVICES

The central product in this chapter is a (digital) marketplace for reusable products. The marketplace has suppliers of materials who can offer their materials for sale, buyers/requesters of reusable materials, and a market master who can connect supply and demand. In fact, the market master is the party behind the (digital) marketplace that sets and creates the conditions. The costs that this process entails, and the value that the connection between supply and demand creates, are the basis for the compensation for the services of the market master. Compensation from which the market master must be able to pay the costs for the digital marketplace.

Supply and demand are digitally matched and implemented by exchanging ownership rights to the materials, not necessarily by changing the physical presence of the materials. This can remain in the depot, or even within a building, if the materials have not yet been released from the building itself.

12. 4. METHODS, TECHNIQUES, TEMPLATES AND INSTRUMENTS

The product of the marketplace is made accessible by means of an IT application, which allows buyers and sellers to connect with each other. A digital marketplace, connected to the digital material database and the property rights module via blockchain technology. The Blockchain registration gives us the possibility to track and trace products by means of the way the blockchain is organized, i.e., each new owner in a chain of activities or ownership means that an additional block or ledger is added. In this way, the succession of sold products can be followed.

Other resources include:

- Various follow-up templates and standardized follow-up documents related to material transactions.
- Templates related to traceability and tracking of materials.

12. 5. RESULTS

The outcome of a marketplace is the successful transaction, expressed both in terms of transaction volumes and the total value of transactions.

12. 6. QUALITY FACTORS

To function properly as a market, a market must meet the following requirements:

1. The quality of the materials to be traded must be transparent.
2. Ownership of the materials must be transparent and legally secured.
3. Access to the market and the conditions for selling and purchasing materials should be made transparent.
4. The prices of the materials must be maintained continuously.
5. The settlement of purchase agreements should be able to be settled automatically.
6. When settling a purchase agreement, the buyer must be able to indicate whether the materials should be delivered and, if so, to which physical location.
7. The financial settlement of transactions on the digital market and the compensation for these transactions for the market master must be able to be settled automatically.

12. 7. PROCESS ACTIVITIES

When trading reusable materials in a (digital) marketplace, the following process activities are involved:

1. The physical setting up of the marketplace in the form of a digital application.
2. The legal structure of the marketplace allows buyers and sellers to enter the digital marketplace.
3. Publish information on marketplaces. To date, there are several well-known existing e-marketplaces. They are different for each country and between regions. Some e-marketplaces are *"national"*, but 90% of the published elements are in a specific area. Try to find an e-marketplace that has been introduced in your area. Let information about the destination of the product (to be stored, directly implemented, sold…) be indicated by the intended stakeholder. Additional aspects are discussed and checked.
4. Send information by email to your network (all actors previously identified), publish information on your own website.
5. The legal shaping of transactions on the market in the form of agreements that can be settled automatically, both in terms of transfer of money, in terms of physical delivery, and in terms of remuneration for the market master.
6. Organizing management and supervision of the market and the various transactions
7. Applying a process of continuous improvement.

The following comments can be made about this chapter.

- Management of the dismantled products via the dismantling company
- Control of the dismantling works and storage via the architectural or engineering firms
- Use accurate and serious traceability methods, documents, and tools. The applicability must be clear in all tenders.
- If you have a physical warehouse, add a digital method/tool to track transactions. Also define delivery, entry, security and exit rules.
- Push to use/sell the products quickly. The longer the time between a match of supply and demand, the higher these costs will be, including loss through use, which can be visualized by the discount rate of loss of value of materials in depots.
- Define the mode of transport and packaging in advance for transport (do not wait until the last day). Ask construction companies or specific suppliers how new products are packaged, search the internet and reuse reports/manuals.

12. 8. QUESTIONS AND ANSWERS

The following questions have been addressed in projects on this topic. Each question has an answer.

Question: Do you or your customers use an internal marketplace for materials?

Respondent 1: Not yet. We are developing, in collaboration with other companies, a physical platform to store the deconstruction materials and elements. It should be launched in 2022.

Respondent 2: Yes, we have an internal marketplace.

Question: How do you or your clients calculate the value of reused materials? From an internal (market)place prespective or with the help of an external marketplace?

Respondent 1: An estimated valuation is made by the company responsible for the assessment of the project (consultant), based on their contacts. The demolition company calculates the demolition costs with respect to the treatment required by the consultant.

Respondent 2: Not done yet. The first approximation should be ¼ to a third of the price for new material.

Respondent 3: We have no experience with this yet. The consultant is currently investigating which method can be used for this.

Respondent 4: The company responsible (consultant) makes an approximate estimate. The deconstructor values the demolition costs with respect to the treatment that the consultant needs.

Respondent 5: The value of reused material is compared to new material that would have been purchased. This value is not linked to the marketplace.

Question: Are you or your client also selling materials from a building to third parties? Or does that only work for your demolition company?

Respondent 1: Depends on the contract.

Respondent 2: Only for the demolition company. Sale of the materials via the owner (CFL). Test on the pilot site Ettelbrück

Respondent 3: Not relevant to date. In the upcoming construction work there will also be sales for third parties

Respondent 4: Depends on the contract.

Respondent 5: Yes, we can sell materials to third parties.

12. 9. COMMENTS

The institutional design of a circular economy

In chapter 2, as well as in paragraph 1 above, we looked at the time factor in the framework of a qualitative cost-benefit analysis. We also call this the institutional design of a circular economy. Many economists have already written about this design. In the following, we apply these insights to the preconditions for a circular economy, which also gives us a grip on the issue of time. As well as on the organization of the futures contracts for materials that are still present in a building, but do not yet have a future destination.

The topics we will discuss are:

1. Asymmetric information,.
2. The lack of property rights and the transaction costs associated with this,
3. Special properties of materials,
4. The role of institutions for a circular economy, including law, organizations and the market and finally
5. The organization of common goods, such as a river, the raw material stock stored in buildings (urban mines) the time factor, or the information that is available about buildings and the built environment.

A. Reducing Information Asymmetry: Akerlof and the *"Lemons"* Problem

One of the key economic challenges in establishing future transactions for reused building materials is the problem of information asymmetry. George Akerlof, in his influential work, The Market for Lemons (1970), showed how markets for second-hand goods often fail when buyers and sellers do not share the same level of information about the quality of a product. In such cases, the buyer – unable to distinguish between high-quality and low-quality items – assumes a significant risk and is only willing to pay a low price. As a result, sellers who do possess high-quality goods are discouraged from participating, since they cannot convey that value credibly to the buyer. The outcome is a downward spiral: high-quality products are withdrawn, trust erodes, and the market collapses into a narrow, low-value niche.

This dynamic is highly relevant for the reuse of building materials. Without accurate, accessible, and trusted information about the quality, provenance, and performance of materials, buyers are unlikely to take the risk of reusing them. Even materials that are in excellent condition may be excluded from the market, simply because their quality cannot be guaranteed. Consequently, the circular economy in construction is severely limited – not by the physical properties of the materials, but by the lack of information about them.

People living down the stream choose to buy bottled water from the facility upstream, rather than drink the water from the river, even if the water may (sometimes) be drinkable.

C-BIM addresses this challenge by systematically documenting material properties throughout their lifecycle. This includes not only the type and location of materials, but also characteristics such as disassembly potential, historical use, and maintenance status. By making this information reliably available across time, C-BIM reduces information asymmetry between current owners and future users. In economic terms, it creates the conditions for a functioning market in which reused materials are valued more accurately, and transactions can take place with greater confidence and fairness.

B. Lowering Transaction Costs: Coase and Ownership Structures

Ronald Coase, in his foundational work The Problem of Social Cost (1960), emphasized the importance of clearly defined property rights in resolving complex societal challenges. He argued that when ownership is unambiguous and transaction costs are low, individuals and organizations can often resolve conflicts or manage shared resources efficiently, without heavy external intervention. However, when transaction costs are high – due to uncertainty, lack of trust, or insufficient information—solutions become more difficult to implement, and valuable exchanges may never occur.

This insight is highly relevant for the circular economy, where reused materials must often change hands across time and context. In the absence of clear ownership and traceability, significant transaction costs arise. Buyers and sellers must invest heavily in verifying quality, confirming liability, or even locating materials in the first place. These frictions can make reuse economically unviable, even when materials themselves are perfectly serviceable.

C-BIM offers a pathway to reduce these transaction costs by establishing both informational and legal clarity around materials. Through detailed documentation and the assignment of unique identifiers to components within a building, C-BIM creates the foundation for material ownership rights that can persist through time. Technologies such as blockchain can reinforce this framework, ensuring that ownership and usage history are securely recorded and transparently updated. This makes it possible to know, at any point in the future, who holds the rights to a given material and under what conditions it can be transferred or reused.

As highlighted by Ramon Hingorani in the context of the SUM4Re project, information plays a crucial role in reducing transaction costs related to the reuse of materials – such as steel beams – by making their provenance and quality traceable and verifiable. By reducing ambiguity and the effort required to negotiate future reuse, C-BIM helps transform circularity from a complex, niche activity into a scalable, accessible economic system – one that is not limited to large players with the means to invest heavily in uncertain long-term returns.

Firms and people face large transaction costs in case they bargain bilaterally with all other parties located onto to the river.

Understanding Asset Specificity: Williamson and the Nature of Materials

Oliver Williamson expanded on Coase's insights by analysing how different transactions incur different costs depending on the characteristics of the goods or services involved. His theory of asset specificity shows that certain assets are highly specialized and context-dependent, making them less interchangeable and harder to transfer without incurring additional costs. The more specific an asset is to a particular use or setting, the greater the transaction costs involved in reassigning or reusing it.

This is highly relevant for materials in the built environment. Some materials – such as standardized bricks or timber – may be easily reused across different contexts. Others, however, are far more specific. A material's toxicity, its disassembly complexity, or the difficulty in transporting it due to its size or integration within a larger structure, all contribute to its specificity. These characteristics make future reuse or resale more complicated and uncertain unless such information is clearly documented and made available to potential future users.

In this way, C-BIM not only builds on the ownership structures outlined by Coase but also provides the detailed material-level intelligence needed to evaluate and reduce asset specificity in practice. By documenting how a material is embedded within a building, whether it is safely separable, whether it contains hazardous substances, or how easily it can be repurposed, C-BIM creates the preconditions for future transactions that would otherwise be too costly or complex to pursue.

Williamson also reminds us that accurate, structured information can generate new possibilities – products and services that emerge not just from the asset itself, but from the system around it. Much like a river enables fishing, electricity generation, and drinking water once we understand and manage it, the documentation of building materials can support the creation of broader circular services. These might include digital material marketplaces, insurance models for reused materials, or cooperative reuse logistics. As more actors gain access to this information, economies of scale and scope emerge, making it feasible for a wider range of organizations and individuals to participate in and benefit from the circular economy.

Water has many uses, specific to each party. This also affects the type of information one would need to decide on the usability of that water.

Enabling Future Markets: North and the Role of Institutions

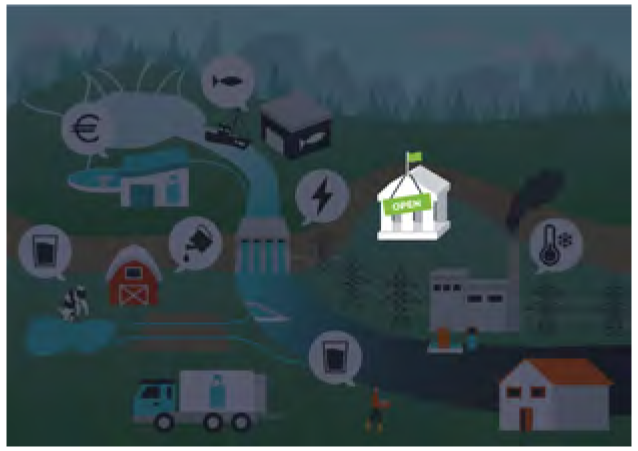
As we have seen, future transactions are central to the functioning of a circular economy in construction. But what makes such transactions possible – especially when they must unfold over extended time frames? Douglass North, through his historical work on the rise of capitalist economies, investigated the institutional conditions under which economies emerge and evolve. His insights are just as relevant today for designing new economic systems, such as a circular economy for the built environment.

North emphasized that goods and services only become viable objects of investment if future returns can be reliably linked back to those who bear the costs today. In other words, transactions in the future must be institutionalized, made credible and enforceable through shared structures – such as contracts, ownership regimes, financial instruments, and public governance. Without such institutions, there is no incentive to invest in the future of a material or product, and thus no basis for a functioning market.

C-BIM supports this institutional foundation by making future transactions thinkable and trustworthy. By ensuring that a material's identity, condition, and ownership can be tracked over time, C-BIM enables the creation of financial connections and contractual arrangements that stretch across decades. It provides the kind of clarity that banks, insurers, regulators, and other institutional actors require to support circular practices at scale.

North's work also reminds us that markets are not built on individual exchanges alone, but on shared infrastructure. One of the most critical infrastructures in the circular construction economy is its data ecosystem. Data about materials in buildings – such as type, quantity, condition, and reusability – functions as a non-rival good: one actor's use does not diminish its availability to others. Yet, paradoxically, this very quality discourages investment. If one organization funds the creation of material data, others can benefit without contributing, leading to underinvestment in these vital commons.

C-BIM thus points toward a new kind of digital commons – a shared, collectively maintained layer of information essential for circular transactions. But as North would argue, for such a commons to flourish, governance mechanisms must ensure fair contribution, access, and quality control. Only then can data become a true enabler of long-term circular value creation.



Once an institution opens in the river's vicinity, it can create a credible source of law and its enforcement. Involved parties will believe that their more environmentally friendly use of water will be rewarded.

Managing the Commons: Avoiding Overuse and Ensuring Sustainability

The insights of Akerlof, Coase, Williamson, and North help us understand why accurate, trustworthy, and temporally anchored information is essential to enable future transactions in a circular construction economy. Akerlof showed us how asymmetries of information can destroy trust and stall markets. Coase emphasized the role of clear ownership structures in reducing transaction costs, while Williamson pointed to the material-specific complexities that must be made transparent to enable reuse. North reminded us that such future-oriented transactions only become viable within institutional frameworks that link investment today to the outcomes tomorrow.

Yet even with these conditions in place—reliable information, reduced transaction costs, ownership clarity, and enabling institutions—a final question remains: how do we govern the infrastructure that makes all this possible? The data systems, platforms, and shared knowledge bases that underpin circularity are themselves a form of commons. If mismanaged, they risk becoming bottlenecks rather than enablers. It is here that Elinor Ostrom's work becomes crucial, offering a framework for managing these shared resources in a way that is equitable, resilient, and adaptive to local conditions.

Tragedy of the Commons

The concept of the tragedy of the commons highlights the difficulties that arise when shared resources are overused or mismanaged. It is not only underinvestment in common goods that poses a risk; even when infrastructure is available, its unregulated or uncoordinated use can lead to overload or degradation. We see this in everyday life – on congested highways, in overfished oceans, or in historical examples of overgrazed communal lands.

In the context of a circular construction economy, the same logic applies. Such an economy can only thrive if it rests on a robust and accessible information infrastructure – one that enables many actors to contribute, participate, and transact. This infrastructure itself is a form of commons: non-rival, collectively beneficial, and vulnerable to both underinvestment and misuse.

To avoid these pitfalls, governance becomes essential. Elinor Ostrom's work offers a powerful counterpoint to the classic tragedy: she demonstrated that communities are capable of self-organizing and sustainably managing commons through local institutions and shared rules. Rather than relying solely on state regulation or market privatization, Ostrom emphasized the role of context-sensitive, participatory governance structures. She showed that, under the right conditions, users of a shared resource can craft their own arrangements that ensure both fairness and sustainability.

Applying Ostrom's principles to the digital infrastructure behind C-BIM, we see the importance of carefully defining access rights, usage norms, and contribution mechanisms. As participation scales up, the challenge becomes how to manage complexity without eroding collective ownership. Overly centralized control or one-size-fits-all regulation may ignore local needs and dynamics, reducing trust and participation. At the same time, total decentralization without shared standards risks fragmentation.

To maintain the dynamic equilibrium needed for a circular ecosystem, governance of the commons must remain adaptable, inclusive, and transparent. Only then can the underlying information infrastructure support not just isolated transactions, but a flourishing and widely accessible circular economy.

Designing Commons-Based Governance for a Circular Economy

Elinor Ostrom's work not only teaches us that commons can be successfully managed, but also how. One of her key contributions is the recognition that in building a circular economy, we must carefully distinguish between public, private, and common elements. While not everything can or should be governed as a commons, shared infrastructures – such as the information systems underpinning C-BIM – require particular care.

Ostrom emphasizes that the success of a commons depends on the ability of diverse groups to create, maintain, and use the resource, while collectively ensuring its sustainability. In a circular construction economy, this means that material data must be reliably produced, updated, and made accessible across stakeholders, but with safeguards to prevent overuse, fragmentation, or degradation of the system.

To guide the creation of such an ecosystem, Ostrom formulated a set of design principles that have been observed in well-functioning commons worldwide. These principles provide a powerful framework for structuring the governance of a circular economy's data infrastructure – especially at the regional or sectoral level. They include:

1. **Clearly defined boundaries:** It must be clear who has access to the resource, and under what conditions. For C-BIM, this means knowing who can read, write, or contribute to material data.
2. **Adaptation to local conditions:** Governance rules must be tailored to local needs, cultures, and capabilities, avoiding top-down uniformity.
3. **Inclusive decision-making:** Those affected by the rules must have the right to participate in modifying them.
4. **Monitoring by the community:** Users themselves should be involved in overseeing proper use of the commons.
5. **Graduated sanctions:** Misuse should be addressed through proportionate penalties, not rigid punishments.
6. **Accessible conflict resolution:** Low-cost, trusted mechanisms must exist to resolve disputes among stakeholders.
7. **Recognition of self-governance:** External authorities must acknowledge and support community-based governance arrangements.
8. **Nested governance:** For large-scale systems, multiple layers of organization are needed, each addressing issues at the appropriate scale.

These principles offer a roadmap for transitioning from isolated pilot projects and fragmented data platforms to a coherent, sustainable infrastructure for circular material flows. They also reinforce a key idea throughout this document: that circularity is not only a technical or economic challenge, but a fundamentally institutional and organizational one.

Enabling Commons Governance through Blockchain

The principles of commons-based governance outlined by Elinor Ostrom provide a conceptual foundation—but translating these principles into practice, especially at scale, presents significant challenges. This is where blockchain technology can play a crucial role. Due to its decentralized and transparent nature, blockchain offers technical mechanisms that align closely with several of Ostrom's design principles, particularly in the context of managing shared data infrastructures for Circular BIM (C-BIM).

First, blockchain allows for a decentralized form of control over shared resources. Rather than relying on a central authority to manage data integrity or enforce access rules, blockchain enables governance through code and consensus. This aligns with Ostrom's emphasis on self-governance and monitoring by the community. Participants in the commons – such as building owners, designers, material suppliers, or demolition contractors – can be granted access only if they also contribute to the collective system, whether by providing verified data, maintaining information, or abiding by agreed-upon protocols.

This enforceability is key to addressing one of the central problems highlighted by Ronald Coase: the difficulty and cost of organizing ownership and accountability. With blockchain, ownership of materials and their corresponding data can be uniquely and immutably registered, allowing for transparent tracking of responsibilities over time. The cost of verifying claims and resolving disputes is reduced, thereby lowering transaction costs.

Moreover, blockchain can also help resolve the information asymmetries that George Akerlof warned about in his *"Market for Lemons."* High-quality material data – verified, time-stamped, and traceable via blockchain – reduces the risk for future buyers and increases trust in second-life materials. In this way, blockchain rewards useful information and enables a functioning market for reused products that would otherwise remain stuck in mistrust and undervaluation.

While blockchain is not a silver bullet, its structural properties make it a natural fit for supporting the collaborative, transparent, and rule-based governance systems that a circular construction economy demands. Used wisely, it can help scale the commons in both reach and legitimacy – ensuring that C-BIM becomes not only a technical tool, but also an institutional cornerstone of circularity.

12. 10. REFERENCES

No references have been added to this chapter.

CONCEPTS

Construction waste: The total product loss due to breakage during transport, product loss due to damage/breakage on the construction site, sawing waste on the construction site and additional materials ordered (3.42) (for smooth process flow)

Construction product: Product (3.60) that is delivered to the construction site and after processing forms part of an element (3.21)

Circular construction: Development, use and reuse (3.29) of buildings, areas, and infrastructure, without unnecessarily depleting natural resources, polluting the living environment, and damaging ecosystems by using as many renewable raw materials as possible (3.31). Circular construction is building in a way that is economically, socio-culturally and ecologically responsible, in the Netherlands and beyond, now and in the future.

Circular economy: An economic system in which the use and value of raw material flows are optimized, without hindering the functioning of the biosphere and the integrity of society [*SOURCE: Platform CB'23 Lexicon circular construction*]. In a circular economy, the aim is to protect biological and technical material stocks, to avoid environmental impact and to preserve existing value.

Sustainable development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs [*SOURCE: Platform CB'23 Lexicon circular construction*]

Element: (Abstract) part of a (building) work (3.11) that is distinguished solely based on a required function [*SOURCE: Framework for circular construction version 1.0*] Examples of elements are spatial separation, supporting structure, lighting, heating, and security.

Physically scarce material: Material (3.42) that is limited in natural resources, that is, scarce based on available raw material stocks and the risk of their depletion.

Raw material: Basic material that is used in a process to make goods, energy, construction products (3.10) or semi-finished products [*SOURCE: Platform CB'23 Lexicon circular construction*]

Reuse: Reusing constructions, building products (3.10), or building or civil engineering work components/elements (3.21) in the same function, with or without processing [*SOURCE: Platform CB'23 Lexicon circular construction*] Reuse is one of the R-principles. Examples of reuse are reusing insulation material as insulation material, a door as a door and a roof as a roof.

Renewable material: Material (3.42) produced from renewable raw material (3.31) [*SOURCE: Platform CB'23 Lexicon circular construction*]

Renewable resource: Resource (3.28) from a source that is grown, or naturally replenished or cleaned on a human timescale (3.46) [*SOURCE: Platform CB'23 Lexicon circular construction*] A renewable resource can be depleted but continue to exist indefinitely with good stewardship. Examples include trees in forests, grass in grasslands, fertile soil. A renewable resource can be of both abiotic and biotic origin.

High-value reuse: Process of converting secondary raw materials (from reuse or recycling) into new materials, components, or products of better* quality, functionality, and/or higher value.

Low-value reuse: The process of converting secondary materials (3.70) components or products (3.60) from reuse (3.29) or recycling (3.63) into new materials (3.42), components or products of lower quality, reduced functionality or lower value than their original application 269 [*SOURCE: Platform CB'23 Lexicon circular construction*] Contamination and mixing, among other things, can result in low-value instead of high-value reuse.

Life cycle: Successive and interrelated stages of a product (3.60) or service system in its current function and at its current location: design, raw material extraction, production, distribution, use and end-of-life treatment (3.22) [*SOURCE: Platform CB'23 Lexicon circular construction*]

Life cycle assessment (LCA): Method for determining and evaluating the input (3.33) and output flows (3.57), and potential environmental impacts (3.47) of a product system (3.62) during its life cycle (3.36) [*SOURCE: Platform CB'23 Lexicon circular construction*]

Removability: Degree to which a composite construction product (3.10) or element (3.22) can be taken apart non-destructively [*SOURCE: Platform CB'23 Lexicon circular construction*] Preferably, detachable construction products or elements are as easy to take apart as possible. The synonym for 'detachable' is sometimes 'demountable'.

Material: Processed raw material (3.27) used for the manufacture of construction products (3.10) [*SOURCE: Platform CB'23 Lexicon circular construction*]

Material balance: The counting of components that make up a system or process under study. A material balance is the result of a material flow analysis.

Material flow analysis MFA: Analytical method to analyze material flows within a well-defined system.

Materials passport: Digital documentation of a (partial) object (3.15) in the B&U or GWW sector stating what a (partial) object consists of - both qualitatively and quantitatively - how it is constructed and where it is located [*SOURCE: Platform CB'23 Lexicon circular construction*]

Environmental performance of buildings MPG: Summary of environmental costs (3.49) per gross floor area [*SOURCE: Platform CB'23 Lexicon circular construction*]

National Environmental Database (NMD): Database with product cards (3.61) and associated environmental profiles (3.53), which is used to determine the environmental performance (3.51) of buildings (3.11) [*SOURCE: Determination method for environmental performance of buildings*]

Non-renewable resource: Resource (3.28) of abiotic or biotic origin that is not grown on a human time scale (3.46), naturally replenished or naturally cleaned and/or does not come from a production unit that is managed sustainably (3.17) [*SOURCE: Platform CB'23 Lexicon circular construction*]

Primary material: (Construction) material (3.42) produced from primary raw materials (3.59) [*SOURCE: Platform CB'23 Lexicon circular construction*]

Primary raw material: Raw material (3.28) that is produced by the earth and that is used by people for the production of materials (3.42) and products (3.60) [*SOURCE: Platform CB'23 Lexicon circular construction*]
Product that is marketed by the supplier and purchased by the customer for use during the life cycle of a building (3.11) A product can be a physical product (for example 1 m² of window frame), but also an activity (for example 1 km of rail transport). [*SOURCE: Method for determining environmental performance of buildings*]

Recycling: The recovery of materials (3.42) and raw materials (3.28) from discarded products (3.60), and the reuse of these to make construction products (3.10) [*SOURCE: Platform CB'23 Lexicon circular construction*]. Recycling is one of the R-principles.

Repair: Longer use of construction products (3.10) or buildings (3.11) through preventive or corrective maintenance (3.56) during the usage phase [*SOURCE: Platform CB'23 Lexicon circular construction*]

Residual value: Market value of products (3.60) and raw materials (3.28) at the end of their useful life and technical lifespan (3.77) respectively [*SOURCE: Platform CB'23 Lexicon circular construction*] Repairing is one of the R-principles.
R-principles circular strategies (3.14) that all start with an R in English [*SOURCE: Platform CB'23 Lexicon circular construction*]
In various R-lists there are 7 to 10 R-principles. Examples of R-principles are recycling, reuse, and maintenance. R-principles are often used to think about and improve circularity. The R-principles include reuse, repair, and recycling. The most significant difference between the R-principles and the core measurement method is that the core measurement method measures circular impact. The R-principles can only be used to see whether a circular strategy has been used. The starting point of the core measurement method is that it can measure the impact of every circular strategy, including that of the R-principles. The R-principles are often presented in a ladder. The suggestion is that a strategy higher on the ladder contributes more to circularity. However, the circular impact differs by application. The core measurement method can make these differences visible, the R-principles cannot.

Recycling: Recovering materials and raw materials from discarded products and reusing them to make products.

Secondary material: Material (3.42) that replaces primary materials (3.39) or other secondary materials and originates from previous use or from residual flows from another product system [*SOURCE: Platform CB'23 Lexicon circular construction*]

Secondary material from reuse: Material (3.20) that is part of a composite (part) object (3.15) that is reused for the same function after a previous application (with or without processing)
Secondary material from recycling material (3.42) that has undergone a recycling process (3.63) and is reused in a (partial) object (3.15)

Socio-economically scarce resource: Resource (3.28) that is scarce in terms of supply and economic importance.

Socio-economically non-scarce resource: Resource (3.28) that is not a socio-economically scarce resource (3.73). Materials that are not on the list of critical materials [11] are also considered socio-economically non-scarce.

Technical cycle: Cycle in which products (3.60), components and materials (3.42) are repaired (by human action) so that they can be used again in the economy as new products, components, and materials [*SOURCE: Platform CB'23 Lexicon circular construction*]

Value retention: High-quality reuse (3.29) of (partial) objects (3.15) and/or their raw materials (3.28). Value retention is maximized by pursuing a comparable or higher-quality functionality when reusing.

SUM4Re

Creating materials banks
from digital urban mining

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